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17491 U.S. PTO 60/500435 09/05/03

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EU 982357241 US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Mark	Shuster	Houston, Texas

☑ *Additional inventors are being named on the* one *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

EXPANDABLE TUBULAR TOOL

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number 000027684 *Type Customer Number here* → *Place Customer Number Bar Code Label here*

OR

☑ Firm *or* Individual Name	Todd Mattingly				
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ENCLOSED APPLICATION PARTS ***(check all that apply)***

☑ Specification *Number of Pages* 112
☐ Drawing(s) *Number of Sheets*
☑ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
☑ Other (specify) Return Receipt Postcard

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☐ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees
☑ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 08-1394
☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($): $160.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.
☑ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are: ______________

Respectfully submitted,

SIGNATURE Todd Mattingly / vmm

Date 09/05/2003

TYPED or PRINTED NAME Todd Mattingly

REGISTRATION NO. *(if appropriate)* 40,298

TELEPHONE 713-547-2301

Docket Number: 25791.304

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

EXPRESS MAIL NO. **EU 982357241 US**

DATE OF DEPOSIT: **September 5, 2003**

The Provisional Application for Patent Cover Sheet, Initial Information Data Sheet and the following one hundred twelve (112) pages are being deposited with the U.S. Postal Service Express Mail Post Office to Addressee Service under 37 CFR §1.10 on the date indicated above and is addressed to: MAIL STOP PROVISIONAL PATENT APPLICATION, Commissioner for Patents, P. O. Box 1450, Alexandria, VA 22313-1450.

Vikki M. Meriwether (25791.304)	Vikki M. Meriwether
Name of person mailing paper and fee	Signature of person mailing paper and fee

EGT-2003-25

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World Leaders in Equipment and Technology for Hydraulic Tube Expansion

July 31, 2003

PHASE ONE -
$10,400.00

TO: Mr. Mark Shuster - Enventure Global Technology
Email: mark.shuster@haliburton.com

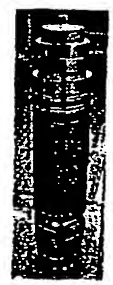
FROM: Russell Wasson

RE: HydroPro Hydro-forming tooling test and evaluation

Dear Mr. Shuster,

The following represents the results of our recent fabrication and testing of a HydroPro mandrel for expansion of a piece of Enventure supplied tubing (pipe). Evaluation was made of the overall performance of the tooling and the extent to which a free expansion of the aforementioned pipe could be accomplished.

TOOLING:



Tooling was manufactured to standard HydroPro design criteria (see attached dwg. - Attach. 1). Tooling had an outside diameter of 4.900" an overall length of 22", weight as assembled of 110 lbs, and an effective expansion zone of 8 – 10".

TUBE:

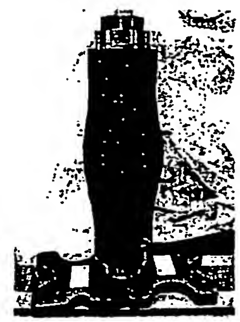
Tube (pipe) was 36-1/2" overall in length and was subsequently cut into two (2) 18-1/4" long sample pieces. Material was basic carbon steel (mild steel) welded seam construction and showed some ovality (approx. 0.030" diametrically). Inside diameter measured 4.925" – 4.945" with a 0.300" average wall.

TESTING:

Mandrel assembly was inserted and centered within test sample and pre-filled to remove air. Tube was subsequently pressurized using the SleevePro system to yield and held at a constantly yielding state until final growth was achieved. The test was halted at what we judged to be a more than adequate degree of expansion for proving capabilities of the tooling, tubing, and process. Both pressure and movement (growth) were tracked in real time. Both diametrical growth and shrinkage of overall length were monitored.

1

TEST RESULTS:



Initial yield was sensed at 1,500 psi, and was tracked through a linear movement of 0.012" growth as pressure increased to 10,000 psi. At 10,500 psi material went into full plastic deformation and continuously leveled off at 10,500 – 11,000 psi until pressure was removed. Pressure was removed at a point when outside diameter had grown by more than 1.25" at the largest point of growth (actual measurement 6.820" o.d.). Tube had shortened to an overall length of 17-1/2" (9/16" shrinkage). Growth in seal area itself was minimized to ½" diametrically due to lack of resistance in the center portion of the tube.

SUMMARY:

In summary, HydroPro has determined that, based upon the results of our testing that the tubing, tooling, and process are a good candidate for use on full length installation of sleeves from similar materials into a parent tube. A logical, and recommended, next step in the process would be to expand another tube into a representative parent tube. This will give an outer boundary for the sleeve to conform to and result in a more uniform expansion. We would be willing to perform this test at our facility with tubing supplied by you at no additional charge.

I sincerely hope this meets with your requirements. If you have any questions, please call me at 573-732-3318, or send me an email. Thanks again for your interest in our products and we look forward to continued work with you on this project

HydroPro

Russell Wasson
Engineering & Mfg. Mgr.

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EGT-2003-26
8-19-2003
vmm

GS ENGINEERING

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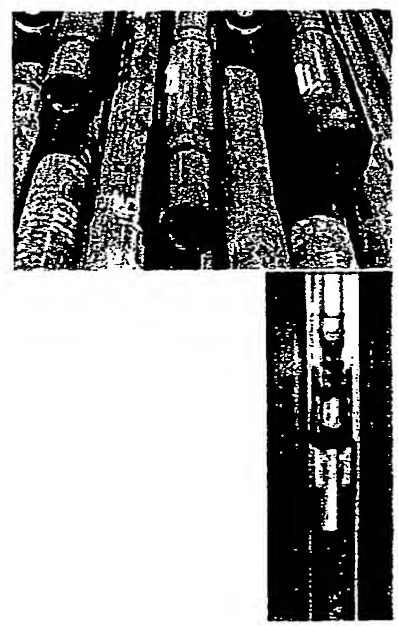
Project Report No. 3205-1

Date: August 11, 2003



Customer:

Enventure Global Technology, LLC
16200A Park Row
Houston, TX 77084

Project Title:

Changeable Diameter Tool Feasibility Study

Distribution:

Mark Shuster

Approvals		
Gr. Grinberg	Date	8/12/2003
Matt Shade	Date	8/12/2003

TABLE OF CONTENTS

1.0 Project Summary

1.1 Project Objective

The primary objective for the first phase of this project was to determine the feasibility of a Two Position Changeable Diameter (TPCD) expandable tubular tool. If a changeable diameter device is feasible, the second objective of this project was to determine the criteria for conceptualization and recommend a direction for the concept design phase. The only tool design requirement specified by GS Engineering was the ability of the TPCD tool to adapt into Enventure's current expandable tubular process.

1.2 Feasibility

1.2.1 Feasibility Criteria

In order to justify feasibility for a changeable diameter tool, several fundamental requirements were selected after analyzing expandable tubular systems. The fundamental system requirements were used to establish feasibility criteria from field case histories, current tool designs and an engineering evaluation. Each criterion was analyzed or investigated until a feasible solution or process could be identified. The list shows the key criteria selected to justify feasibility.

1. Reduce system friction.
2. Robust expandable cone mechanism.
3. Reliable sealing during expansion, Isolate "Mud" below tool.
4. Simple actuation method for expansion and contraction.
5. Simple actuation signal.
6. Minimize the number of components in the tool.
7. Tool material.

1.2.2 Feasibility Conclusion

After an extensive evaluation of each criterion, it was determined that a Two Position Changeable Diameter tool design is feasible for a bottom up expandable tubular process.

✓	FEASIBLE
	NOT FEASIBLE

1.3 Next Steps

The feasibility analysis generated two paths for the conceptualization phase. One path for conceptualization is a Two-Stage tool design. The first stage of the tool is a solid cone that initially expands the pipe and provides a "mud" isolation seal. The second stage utilizes a segmented expanding cone to expand the pipe to its final diameter. A Single-Stage drop-in device is the second path for conceptualization. The second tooling approach also utilizes a segmented expanding cone, but the expanding cone in this situation incorporates an integrated sealing device. The Single-Stage tool cone will expand after being lowered into the well, then the hydraulic fluid "mud" will force the tool up the pipe. The advantages of a drop-in tool are known, but the disadvantages in this case are the lack of experience with a completely new process and a new tool design. The time to market for a Single-Stage tool design and process could be significant. The two-stage tool is definitely the most realistic short-term solution. In this case, we recommend designing a Two-Stage changeable diameter tool while pursuing a Single-Stage (drop-in) tool. The field experience gained with the Two-Stage expandable tool will be leveraged into the design of the Single-Stage drop-in tool in the future.

<u>Action Items</u>

Short Term

- Begin Conceptualization Phase on Two-Stage Tool.
- Lubricant and Cone Surface Testing – EGT project almost complete. (M. Shuster)
- Material Experimentation and Selection – EGT Testing in process. (M. Shuster)
- Actuation System Control Algorithm Development and Testing.

Long Term

- Single-Stage Drop-in Tool Conceptualization.
- Pipe Integrity Testing- Collapse, Leakage, Connector Thread Design.

2.0 Project Description

The low friction expandable tool project was broken into multiple phases due to concerns about the scope and feasibility of the project. In the first stage, the feasibility of an expandable tubular tool with a changeable diameter cone was investigated. If a changeable diameter tool is feasible, the project will continue to the conceptualization phase upon approval by EGT. The conceptualization phase will be followed by a testing and selection phase that will select the best concept and optimum design parameters. The last phase of this project will be the final design.

2.1 Project Objective

The objective of this project was to determine the feasibility of a changeable diameter expandable tubular tool. If a Two-Position Changeable Diameter device is feasible, the second objective of the project will be to determine the criteria for conceptualization and recommend potential avenues for the concept design phase.

The changeable diameter tool should be capable of expanding and contracting from a specific diameter to another specific larger diameter. The expansion and contraction of the cone should be engaged or disengaged based on the pipe expansion or forming resistance. The project will determine the feasibility of a Two-Position Changeable Diameter device, not a variable diameter expansion device. The expansion cone will either be expanding the pipe to the set diameter or be collapsed. A variable diameter device that expands the pipe to any diameter between the set expanded diameter and the collapsed diameter will not be investigated at this time.

3.0 Feasibility Criteria

In order to perform an accurate feasibility study an industry overview was completed to identify the industry competitors and their respective processes. Each of the company's capabilities in the solid expandable tubular area was analyzed by design features and by ownership of intellectual property. The goal was to identify processes used in the industry and understand the problems and limitations of each process. The fundamental process information will be utilized to select criteria to justify feasibility. These criteria along with the best features of each design and process will be used in the selection of conceptualization criteria in the next phase.

3.1 Industry Overview

The three major players in the expandable tubular market are Enventure Global Technology, Baker Oil Tools, and Weatherford[1]. In this section we will outline the industries technical problems with expandable tubulars, characterize the major players processes and analyze the key features and design elements.

3.1.1 Expandable Tubular Pr blems

In the past few years' expandable tubular technology has overcome many technical hurdles. It is now considered mainstream technology with the future directed towards MonoDiameter™ and Slimwell Systems[2] using solid and expandable tools. Even with all of the technical advances and the key future applications on the horizon, many issues still exist. The list below shows the industries primary problems, which may or may not, be directly associated with the solid cone and expanding cone tool designs. Selecting the issues that are directly related to the cone and tool design will be sorted in a later section.

- Pipe Material Property Changes in the Forming Process
- Pipe Connections, Sealing
- Expandable Tool to Pipe Friction
- Pipe Failures – Collapsing, Burst
- Expansion of Thick Wall Pipe[3]
- Risk – Cost of Failure, "New Technology" Paradigm

3.1.2 Process Characterization

The table below shows the key aspects of each company's expandable tubular expansion technique relative to the other processes.

TABLE I

	ENVENTURE GT	BAKER OIL TOOLS	WEATHERFORD
Expansion Method	Solid Cone	Solid Cone	Rotary Cone
Input Load (Force)	High	High	Low
Surface Requirements At Ground Level	High Pressure Supply	High Pressure Supply	Mechanical Rotation From Ground Level Or High Pressure Supply Mud Motor
Forming Method	Cold Working Pipe*	Cold Working Pipe*	Cold Working Pipe*
Forming Effect	Pipe Length Shrinkage Near 4% with Minimal Wall Thickness Reduction[2]	Pipe Length Shrinkage with Minimal Wall Thickness Reduction	Pipe Wall Thickness Reduction with Minimal Pipe Length Shrinkage
Friction Type	Sliding	Sliding	Rotational
Friction Level	High	High	Moderate
Lubrication	None, If used in front of tool wedge	None, If used in front of tool wedge	None, If used in front of rotation tool
Tool Components	No Moving Parts	Few Moving Parts	Many Moving Parts
Relative Tool Cost	Low	Medium	High
Patented Process	Yes	Yes	Yes
Tool Graphic	Figure 1	Figure 2[4]	Figure 3

*The degree of cold working is different for each process and will yield different pipe properties.

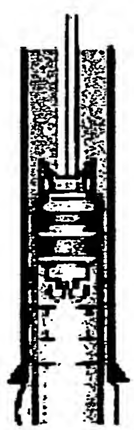


Fig. 1

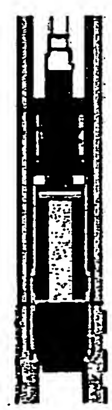


Fig. 2

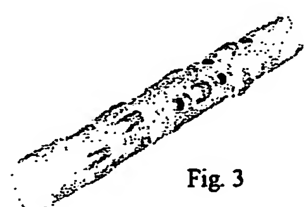


Fig. 3

3.1.3 Design Analysis f Current Expandable Tubular Systems

The designs of the systems above all have advantages as well as disadvantages. The primary purpose of completing this basic comparison was to select the known benefits of each design for possible implementation into a changeable diameter tool design. The advantages and disadvantages were selected from data in articles and in case histories. The results in this section are unique because the conclusions are drawn from reference materials with engineering perspectives. However, the information in the table was subjective based on the author of the reference material. Each item was compared in relation to the other listed processes.

TABLE II

	ENVENTURE GT	BAKER OIL TOOLS	WEATHERFORD
Advantages	✓ Low Tool Cost	✓ Simple Design, Some Moving Parts	✓ Low Working Loads
	✓ Simple Design No Moving Parts	✓ Top-Down	✓ Top-Down
	✓ Minimal Ground Facilities	✓ Minimal Ground Facilities	
Disadvantages	▪ High Tool Friction	▪ High Tool Friction	▪ Complex Design, Many Moving Parts
	▪ Bottom-Up Design		▪ High Wall Collapse Risk
	▪ Risk of Tool Jam		▪ High Tool Cost

3.2 Tool Requirements and Criteria

The feasibility for the TPCD tool was based on a set of criteria. The criteria was established from background information, field experience and an engineering review. These criteria were then used to justify feasibility. The specific focus of this project was on the feasibility of the TPCD tool. The feasibility of other expandable tubular problems, such as, collapse, connection leakage, pipe threads will not be addressed. However, these issues will not be ignored when justifying feasibility of designing a changeable diameter tool.

3.2.1 Tool Requirements

The only tool design requirement specified by GS Engineering was the ability of the TPCD tool to adapt into Enventure's current expandable tubular process. For example, the basic Openhole Liner System (OLS) is shown. The changeable diameter tool should only effect the actual pipe expansion process step. This requirement will limit any changes to the ground facilities or

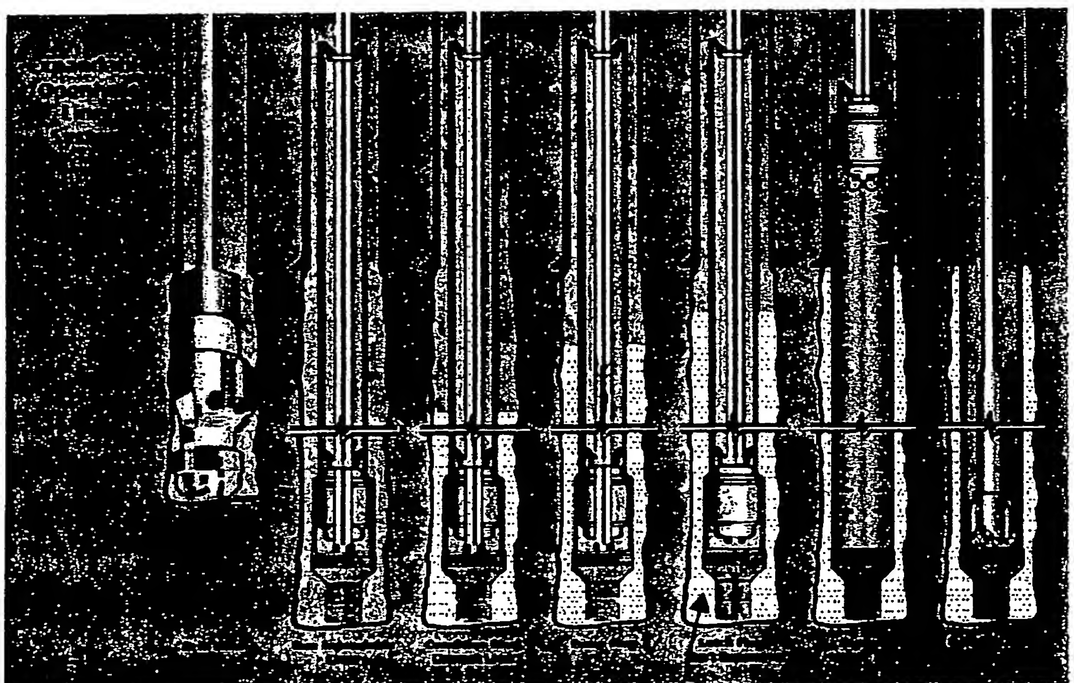


Figure Supplied by EGT.

Pipe Expansion Step

equipment. This requirement however, indirectly specifies the input loading method applied to the tool to expand the pipe and the expansion direction. In this case, the hydraulic fluid "mud" will be the working fluid used in a bottom-up tooling system. The feasibility of a changeable diameter tool must meet these high level requirements.

- **Minimal or no change of ground support, systems or equipment.**
- **Bottom –Up expandable tubular system with "mud" as working fluid.**

3.2.2 Criteria from Backgr und Inf rmati n

The overview of the industry indicated several areas for improvement in the expandable tubular process. The industry desires to increase expansion ratios, reduce input supply pressures and expand thicker walled pipe. All of these areas are indirectly affected by the systems friction. A reduction in friction will reduce input pressure, allow for higher expansion ratios and/or permit the use of thicker wall pipe. The first criterion selected to justify feasibility of a TPCD tool is the ability to reduce system friction.

Feasibility Criteria

1. **Reduce System Friction - Cone to Pipe.**

3.2.3 Engineering Criteria

An engineering analysis of the changeable diameter system revealed another set of feasibility criteria for the TPCD tool components. The tool components must meet certain criteria to be deemed feasible. The first critical component in the changeable diameter system is the expanding cone. The integrity of the expanding cone device and its related components are essential to the feasibility of the tool. The second criterion in a bottom-up hydraulically driven TPCD tool is the seal. The method used to seal the mud below the tool is vital for driving the tool up the pipe. This tool seal must maintain its integrity at its fully expanded position and throughout expansion from the contracted position. The next important component that will effect feasibility is the actuation device and the activation signals that engage or disengage the expanding cone device. The actuator must be capable of expanding the cone segments while experiencing intense loading. The large localized loading of some components may require special materials or coatings. The material of the various components will not be selected in this phase, but will be examined to determine any material limitations. The final criterion relates to the dependability of the tool. Simple systems are always more dependable, so minimizing the number of components and complex motion is important. The list below summarizes the selected engineering criteria. Each of the engineering criteria discussed will be analyzed in the next section to find a suitable process or fundamental design to justify feasibility.

2. **Robust expanding cone mechanism.**
3. **Reliable sealing during expansion.**
4. **Simple actuation method for expansion and contraction of cone mechanism.**
5. **Simple actuation signal.**
6. **Minimize the number of components in the tool.**
7. **Tool Material.**

4.0 Feasibility

4.1 Feasibility Analysis

The analysis will determine if the changeable diameter tool criteria meet the requirements for feasibility. Each criteria will be analyzed independently for feasibility. In some cases potential solutions will be provided. The solutions whether concepts, ideas or designs will be captured for use in the conceptualization phase

[redacted]	**REDUCE SYSTEM FRICTION - CONE TO PIPE**	**Feasible?**	**YES**
[redacted]	The energy saved by reducing friction can be used for pipe forming, actuating the expansion device, reducing input supply pressure or using thicker walled pipe. Research by EGT has shown significant reductions in friction by incorporating high-pressure lubrication, using high performance lubricants and by using various cone surface designs. The hydroelectric high-pressure lubrication assistance concept or multiplicator may be required to provide additional reductions in friction.		
[redacted]	High Pressure Lubrication System, Various Cone Surfaces, High Performance Lubricants		

[redacted]	**ROBUST EXPANDING CONE MECHANISM**	**Feasible?**	**YES**
[redacted]	Several expandable cone mechanisms were investigated as potential means to justify feasibility. The design of a durable expandable cone is mostly limited to a system of independent segments. Research at EGT has shown the effects of cone segment gaps. Once the gap between segments becomes to large, axial slots or grooves form in the pipe. The key to reducing the effect of the cone segments on the pipe ID is the design configuration of the segments. Various assembly configurations with independent segments are possible. The configuration could be a sequence of layered segments or radial arc segments or pie shaped wedges. A wedge design that is utilized by Baker Hughes[5] is shown below. Other functional designs that minimize the gap effect on the pipe I.D. are possible.		

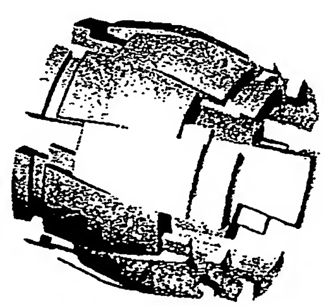


Figure 4

[redacted]	**RELIABLE SEALING DURING EXPANSION**	**Feasible?**	**YES**
	This is the most complex issue in a bottom-up tooling system. Sealing an expandable cone, which consists of multiple expanding segments, continuously during expansion and retraction is very difficult. This issue will be the key design consideration of every concept. A unique and simple solution is a Two-Stage cone tool. The first stage of the tool is a standard solid cone that begins pipe expansion and the second stage is an expandable cone that expands the pipe to its final dimension. The first stage cone forms the mechanical seal with the pipe isolating the "mud" below the tool. A Single-Stage device with a sealed changeable diameter cone is also possible.		
	Two-Stage tool. (Figure 5)		

[redacted]	**MINIMIZE THE NUMBER OF COMPONENTS IN THE TOOL**	**Feasible?**	**YES**
	The intent of this criteria was to limit or minimize the number of components making up the tool, such as valves, actuators, bearings, cone segments, etc. A simple tool design will control dependability, cost and risk. A relatively simple system is possible.		

[redacted]	**SIMPLE ACTUATION METHOD FOR EXPANSION AND CONTRACTION OF CONE MECHANISM**	**Feasible?**	**YES**
	A feasible system must facilitate one actuator for all expanding cone segments. The preliminary concept shown in Figure 5 uses a hydraulically driven wedge to mechanically expand the cone segments. A feasible design for a simple actuation method is possible.		

[redacted]	**SIMPLE ACTUATION SIGNAL**	**Feasible?**	**YES**
	The control method for actuation is another key element that will directly affect the feasibility of the changeable diameter tool. After analyzing a TPCD system, it was determined that actuation control methods such as, mechanical, electrical and/or hydraulic are possible. Some methods are more cost effective than others, but until a final concept is designed, it would be premature to select a control scheme. One possible solution is a tool with a single actuator that is engaged by the tool string and disengaged by a "mud" pressure limit switch. In this case, when the mud pressure exceeds a preset limit, the actuator will be disengaged and retract the expandable cone. One example was shown, but many control algorithms for a changeable diameter tool are possible.		
	Mechanical, Electrical and/or Hydraulic Signal		

	TOOL MATERIAL	Feasible?	YES
[redacted]	A basic calculation was completed on a segmented cone exposed to typical loading during expansion. The results showed the cone components operating at a level ten times less than the yield strength of a standard tool steel. For this reason the material properties will not limit feasibility. Material properties should not be an issue, but additional requirements maybe necessary to prevent wear, friction and environmental effects.		
[redacted]	Tool steels or high strength, high toughness materials with corrosion resistance will be well suited for this tool. In this case, the loading on the tools forming surfaces (cone surfaces) is extremely high and will prevent the use of coatings. Other components such as the actuator and actuator assembly components may need coating to reduce friction, wear and corrosion. A material selection program is currently underway at Enventure based on materials recommended in GS Engineering Project 3202.		

4.2 Feasibility Result

The feasibility analysis indicates that many issues exist for a changeable diameter tool design. However, after a thorough analysis, it is concluded that no major engineering roadblocks exist which would prevent designing an expandable tool. A design of a changeable diameter tool is feasible.

✓	FEASIBLE
	NOT FEASIBLE

5.0 Next Step

5.1 Paths for Conceptualization

The analysis of the feasibility criteria generated two potential paths for conceptualization. The paths produce a similar result, but employ very different methods. The first path is basically a modification to the existing EGT expandable tubular process. This path consists of a Two-Stage expandable tool. This conceptual idea utilizes the same ground support equipment and launcher, but integrates two cones into one tool. The first stage cone produces a mechanical seal to isolate the working fluid "mud" below the tool. This stage is essentially the current EGT expandable tubular tool with a relatively small pipe expansion ratio and a high-pressure lubrication system. The first stage pipe expansion ratio can be as little as 1% of the overall pipe expansion or enough to create a robust seal. The second stage incorporates a changeable diameter cone that can be expanded or contracted from an input signal. Figure 5 shows the basic conceptual idea. This path for conceptualization is the most realistic for many reasons. The primary reason is based on cost and timing. This conceptual idea is an extension of EGT's current process and technology. This alone will minimize development and time to market.

Test results from Dr. Shuster's team on cone surfaces with high-pressure lubrication helped to justify the Two-Stage path. The EGT team tested two cone surfaces designs for another tool project that was leveraged into the Two-Stage concept. One of the results was for a stepped cone and the other was for a vertically slotted cone. The two steps in the stepped cone test simulated the step from the stage one cone to the stage two cone. The slotted cone test simulated the gap between the expandable cone segments. The results from both cone surface tests did not show any additional frictional effects on the expandable tubular system.

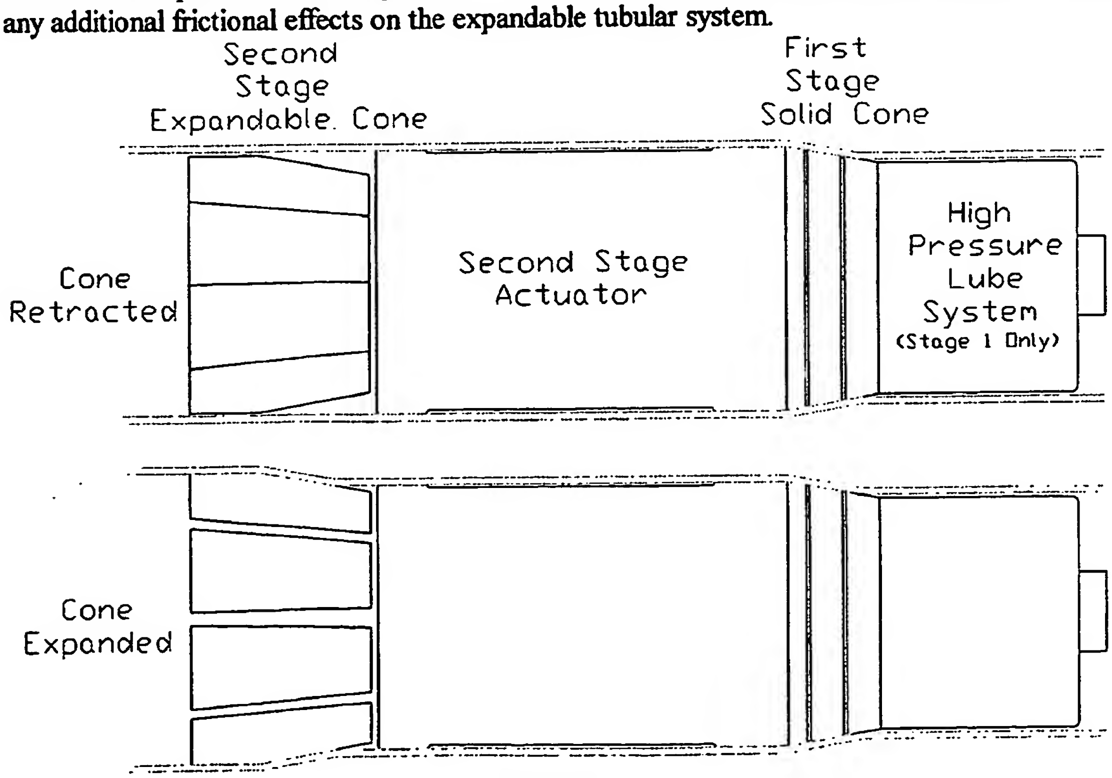


Figure 5

The other path for conceptualization is a Single-Stage changeable diameter tool. This path is the ultimate goal, but will require extensive research and development along with field-testing. The time to bring a functional design to the market will be 2 to 3 times longer than with the first path. The preliminary idea for the second concept path is a changeable diameter tool that could be dropped in the pipe. This tool would expand the pipe with a continuously sealed expanding segmented cone. Even though this device and process seem relatively simple, this concept idea will require a significant amount of testing and development to reach the market.

In both concepts, the Single-Stage and the Two-Stage, development of the tool must take place. The two-stage concept will require less tool design and development effort because of its compatibility with the current Enventure process. The single stage on the other hand may take the same amount of time to design, but testing and development of a new process and all support systems and equipment will be significantly more time consuming. Table III below summarizes the benefits of each conceptualization path.

TABLE III

	Two-Stage Concept Path	One-Stage Concept Path
Advantages	✓ Short Time to Market	✓ No Launcher, Unlimited Pipe Expansion Range
	✓ Simple Design	✓ Top-Down
	✓ No Ground Support Changes	✓ Reusable Tool, Replaceable Cone Segments
	✓ Guaranteed Minimal Expansion (1st stage)	✓ Reduced Risk
Disadvantages	▪ Limited Pipe Expansion Ratio	▪ Some Ground Facilities Changes
	▪ Risk of Tool Jam	▪ More Complex Design
		▪ Longer Time to Market

5.1.1 Intellectual Property Review

Before proceeding to the conceptualization phase a review of patents and patent applications was completed. Two potential conceptualization paths were identified in the previous section. The purpose of the general intellectual property review was to determine if other roadblocks exist which would prevent proceeding down these paths to find an engineering design solution. Over 50 Patents and Patent Applications were reviewed for expandable tooling designs. The cover page of several Patent Applications and Patents reviewed are shown in the Appendix. In summary, after a basic review of published intellectual property, GSE was unable to find any information that would prevent continuing to the next phase. The intellectual property information discussed in this report is preliminary and should be formally review by EGT legal department where necessary.

6.0 Conclusions

The most realistic tooling approach for a changeable diameter tool will be the Two-Stage concept. This option is capable of being implemented in a reasonably short period of time. A Single Stage changeable diameter tool is also feasible, but development time will be much more significant.

7.0 Acknowledgements

GS Engineering would like to thank Dr. Shuster and his team for test results and technical information provided for the project.

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- Weatherford, Website: Weatherford.com
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- Crucible Services Centers, Website: crucibleservice.com
- Petromin, Website: Safan.com
- Alexander's Gas and Oil Connections, Website: gasandoil.com
- Grant Prideco, Website: grantprideco.com

9.0 Appendix

9.1 Patent and Applications Reviewed

9.1.1 Patent Applications

1	20030075339	Wear Resistant, Variable Diameter Expansion Tool and Expansion Methods
2	20030121558	Radial expansion of tubular members
3	20030098154	Apparatus for radially expanding tubular members
5	20030094279	Method of selecting tubular members
6	20030094278	Expansion cone for radially expanding tubular members
7	20030094277	Expansion cone for radially expanding tubular members
8	20030140673	Tubing expansion
9	20030116319	Methods and compositions for sealing an expandable tubular in a wellbore
10	20030047323	Expandable hanger and packer
11	20020139540	Method and apparatus for downhole tubular expansion
12	20020100594	Wellbore casing
13	20020092657	Method of applying an axial force to an expansion cone
14	20020079100	Apparatus, methods, and applications for expanding tubulars in a wellbore
15	20020074134	Apparatus for actuating an annular piston
16	20020185274	Apparatus and methods for expanding tubulars in a wellbore
17	20020100593	Preload for expansion cone
18	20020092657	Method of applying an axial force to an expansion cone
19	20020084078	Method of operating an apparatus for radially expanding a tubular member
20	20020074130	Apparatus for radially expanding a tubular member
21	20010045284	Apparatus and methods for expanding tubulars in a wellbore

9.1.2 Patents

1	6578630	Apparatus and methods for expanding tubulars in a wellbore
2	6,334,351	Metal pipe expander
3	6,470,966	Apparatus for forming wellbore casing
4	6,543,552	Method and apparatus for drilling and lining a wellbore
5	6,557,640	Lubrication and self-cleaning system for expansion mandrel
6	5,101,653	Mechanical pipe expander
7	6,568,471	Liner hanger

US 20030075339A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0075339 A1
Gano et al. (43) Pub. Date: Apr. 24, 2003

(54) WEAR-RESISTANT, VARIABLE DIAMETER EXPANSION TOOL AND EXPANSION METHODS

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(21) Appl. No.: 10/047,628

(22) Filed: Oct. 23, 2001

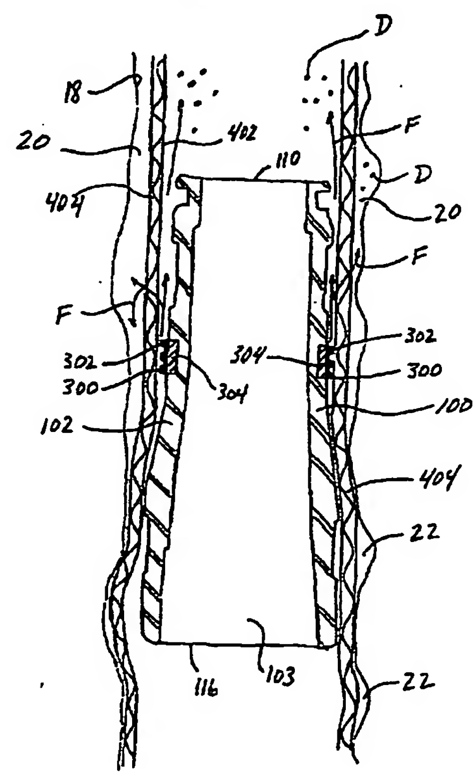
Publication Classification

(51) Int. Cl.^{7} E21B 43/10

(52) U.S. Cl. 166/380; 166/207; 166/383

(57) ABSTRACT

The inventions provide apparatus and methods for radially expanding a tubular deployed in a subterranean well by moving an expansion tool axially through the well. An expansion tool apparatus may have wear faces attached to at least a portion of the outer periphery of a mandrel for contacting the interior surface of the pipe, tube, or screen during expansion. According to another aspect of the invention, an expansion tool has a controlled egress seal between the outer surface of the tool and the inside surface of the expandable tubular. According to another aspect of the invention, an automatically variable diameter expansion tool is provided having a variable diameter cone, which expands, and contracts based on input from one or more sensors. According to another aspect of the invention, an apparatus and method for expanding a length of screen assembly in a subterranean wellbore is provided.



US 20030121558A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0121558 A1**
Cook et al. (43) **Pub. Date: Jul. 3, 2003**

(54) **RADIAL EXPANSION OF TUBULAR MEMBERS**

(76) Inventors: **Robert Lance Cook**, Katy, TX (US); **Richard Carl Haut**, Sugar Land, TX (US); **Lev Ring**, Houston, TX (US); **Thomas Patrick Grant III**, San Antonio, TX (US); **Edwin Arnold Zwald**, Houston, TX (US); **Andrei Gregory Filippov**, (US)

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(21) Appl. No.: 10/303,992

(22) Filed: Nov. 22, 2002

Related U.S. Application Data

(60) Continuation of application No. PCT/US01/19014, filed on Jun. 12, 2001. Continuation-in-part of application No. 09/852,026, filed on May 9, 2001, now Pat. No. 6,561,227, which is a division of application No. 09/454,139, filed on Dec. 3, 1999, now Pat. No. 6,497,289. Continuation-in-part of application No. 09/510,913, filed on Feb. 23, 2000. Continuation-in-part of application No. 09/502,350, filed on Feb. 10, 2000, now abandoned. Continuation-in-part of application No. 09/969,922, filed on Oct. 3, 2001, which is a continuation of application No. 09/440,338, filed on Nov. 15, 1999, now Pat. No. 6,328,113. Continuation-in-part of application No. 10/169,434. Continuation-in-part of application No. 09/523,460, filed on Mar. 10, 2000, now abandoned. Continuation-in-part of application No. 09/512,895, filed on Feb. 24, 2000. Continuation-in-part of application No. 09/511,941, filed on Feb. 24, 2000. Continuation-in-part of application No. 09/588,946, filed on Jun. 7, 2000, now Pat. No. 6,557,640. Continuation-in-part of application No. 09/559,122, filed on Apr. 26, 2000.

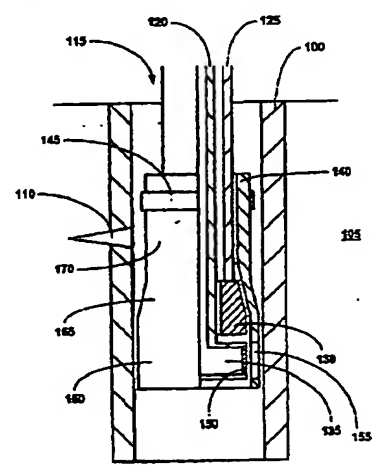
(60) Provisional application No. 60/212,359, filed on Jun. 19, 2000. Provisional application No. 60/111,293, filed on Dec. 7, 1998. Provisional application No. 60/121,702, filed on Feb. 25, 1999. Provisional application No. 60/119,611, filed on Feb. 11, 1999. Provisional application No. 60/108,558, filed on Nov. 16, 1998. Provisional application No. 60/124,042, filed on Mar. 11, 1999. Provisional application No. 60/121,841, filed on Feb. 26, 1999. Provisional application No. 60/154,047, filed on Sep. 16, 1999. Provisional application No. 60/121,907, filed on Feb. 26, 1999. Provisional application No. 60/137,998, filed on Jun. 7, 1999. Provisional application No. 60/131,106, filed on Apr. 26, 1999.

Publication Classification

(51) Int. Cl.7 .... F16L 55/16
(52) U.S. Cl. 138/98; 264/36.16; 138/97; 264/269

(57) **ABSTRACT**

An apparatus and method for coupling a tubular member to a preexisting structure. The tubular member is anchored to the preexisting structure and an expansion member is pulled through the tubular member to radially expand the tubular member.



US 20030098154A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0098154 A1
Cook et al. (43) Pub. Date: May 29, 2003

(54) APPARATUS FOR RADIALLY EXPANDING TUBULAR MEMBERS

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(21) Appl. No.: 10/261,925

(22) Filed: Oct. 1, 2002

Related U.S. Application Data

(60) Division of application No. 09/588,946, filed on Jun. 7, 2000, which is a continuation-in-part of application No. 09/559,122, filed on Apr. 26, 2000, and which is a continuation-in-part of application No. 09/523,460, filed on Mar. 10, 2000, now abandoned, and which is a continuation-in-part of application No. 09/510,913, filed on Feb. 23, 2000, and which is a continuation-in-part of application No. 09/502,350, filed on Feb. 10, 2000, now abandoned, and which is a continuation-in-part of application No. 09/454,139, filed on Dec. 3, 1999, now Pat. No. 6,497,289.

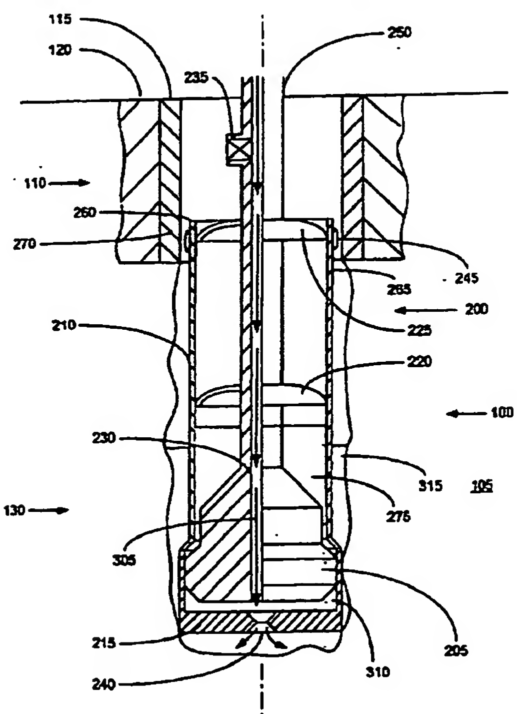
(60) Provisional application No. 60/131,106, filed on Apr. 26, 1999. Provisional application No. 60/124,042, filed on Mar. 11, 1999. Provisional application No. 60/121,702, filed on Feb. 25, 1999. Provisional application No. 60/119,611, filed on Feb. 11, 1999. Provisional application No. 60/111,293, filed on Dec. 7, 1998.

Publication Classification

(51) Int. Cl.[7] E21B 23/00
(52) U.S. Cl. 166/206; 166/207; 166/217

(57) ABSTRACT

An apparatus for radially expanding tubular members.



US 20030094279A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2003/0094279 A1

Ring et al. (43) Pub. Date: May 22, 2003

(54) METHOD OF SELECTING TUBULAR MEMBERS

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(21) Appl. No.: 10/262,009

(22) Filed: Oct. 1, 2002

Related U.S. Application Data

(60) Division of application No. 09/588,946, filed on Jun. 7, 2000, which is a continuation-in-part of application No. 09/559,122, filed on Apr. 26, 2000, and which is a continuation-in-part of application No. 09/523,460, filed on Mar. 10, 2000, now abandoned, and which is a continuation-in-part of application No. 09/510,913, filed on Feb. 23, 2000, and which is a continuation-in-part of application No. 09/502,350, filed on Feb. 10, 2000, now abandoned, and which is a continuation-in-part of application No. 09/454,139, filed on Dec. 3, 1999, now Pat. No. 6,497,289.

(60) Provisional application No. 60/131,106, filed on Apr. 26, 1999. Provisional application No. 60/124,042, filed on Mar. 11, 1999. Provisional application No. 60/121,702, filed on Feb. 25, 1999. Provisional application No. 60/119,611, filed on Feb. 11, 1999. Provisional application No. 60/111,293, filed on Dec. 7, 1998.

Publication Classification

(51) Int. Cl.^{7} E21B 47/00

(52) U.S. Cl. 166/250.01; 166/382

(57) ABSTRACT

A method of selecting tubular members.

US 20030094278A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2003/0094278 A1**
Cook et al. (43) **Pub. Date: May 22, 2003**

(54) **EXPANSION CONE FOR RADIALLY EXPANDING TUBULAR MEMBERS**

(75) Inventors: Robert Lance Cook, Katy, TX (US); David Paul Brisco, Duncan, OK (US); Lev Ring, Houston, TX (US); Alan B. Duell, Duncan, OK (US); Andrei Gregory Filippov, Katy, TX (US)

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(21) Appl. No.: 10/261,927

(22) Filed: Oct. 1, 2002

Related U.S. Application Data

(60) Division of application No. 09/588,946, filed on Jun. 7, 2000, which is a continuation-in-part of application No. 09/559,122, filed on Apr. 26, 2000, and which is a continuation-in-part of application No. 09/523,460, filed on Mar. 10, 2000, now abandoned, and which is a continuation-in-part of application No. 09/510,913, filed on Feb. 23, 2000, and which is a continuation-in-part of application No. 09/502,350, filed on Feb. 10, 2000, now abandoned, and which is a continuation-in-part of application No. 09/454,139, filed on Dec. 3, 1999, now Pat. No. 6,497,289.

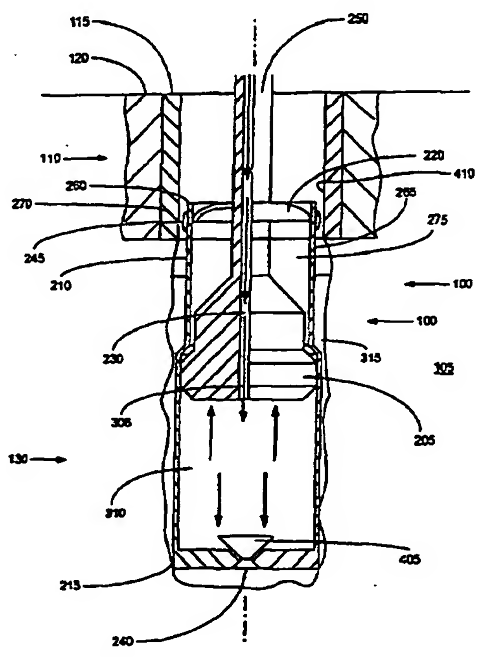
(60) Provisional application No. 60/131,106, filed on Apr. 26, 1999. Provisional application No. 60/124,042, filed on Mar. 11, 1999. Provisional application No. 60/121,702, filed on Feb. 25, 1999. Provisional application No. 60/119,611, filed on Feb. 11, 1999. Provisional application No. 60/111,293, filed on Dec. 7, 1998.

Publication Classification

(51) Int. Cl.⁷ E21B 23/00
(52) U.S. Cl. 166/212; 166/207; 166/217

(57) **ABSTRACT**

An expansion cone for radially expanding tubular members.



US 20030094277A1

(19) United States
(12) Patent Application Publication
Cook et al.

(10) Pub. No.: US 2003/0094277 A1
(43) Pub. Date: May 22, 2003

(54) EXPANSION CONE FOR RADIALLY EXPANDING TUBULAR MEMBERS

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(21) Appl. No.: 10/262,008

(22) Filed: Oct. 1, 2002

Related U.S. Application Data

(60) Division of application No. 09/588,946, filed on Jun. 7, 2000, which is a continuation-in-part of application No. 09/559,122, filed on Apr. 26, 2000.

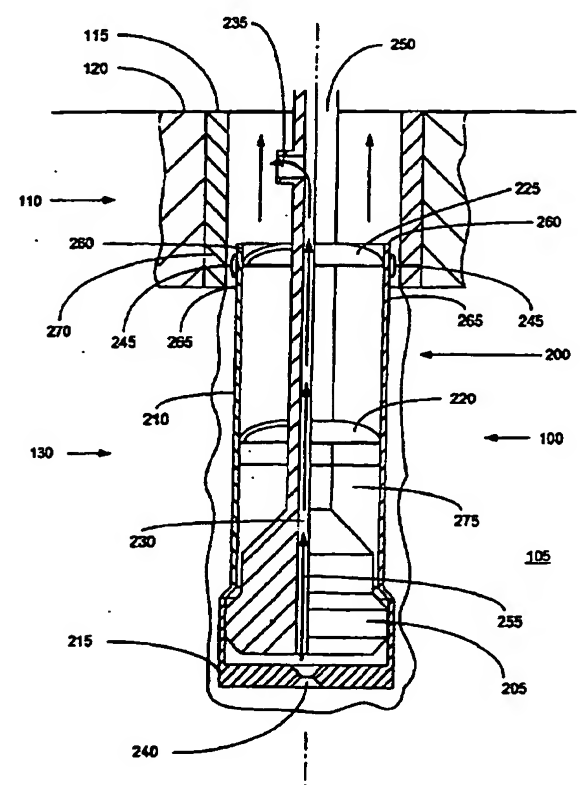
(60) Provisional application No. 60/131,106, filed on Apr. 26, 1999.

Publication Classification

(51) Int. Cl.⁷ E21B 23/02
(52) U.S. Cl. 166/207

(57) ABSTRACT

An expansion cone for radially expanding tubular members.



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US 20030075337A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2003/0075337 A1

Maguire (43) Pub. Date: Apr. 24, 2003

(54) METHOD OF EXPANDING A TUBULAR MEMBER IN A WELLBORE

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(21) Appl. No.: 10/003,968

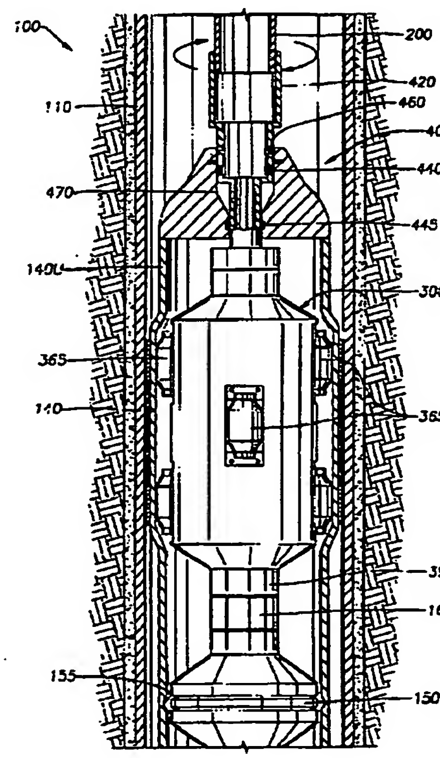
(22) Filed: Oct. 24, 2001

Publication Classification

(51) Int. Cl.[7] E21B 23/00
(52) U.S. Cl. 166/380; 166/207; 166/384

(57) ABSTRACT

The present invention provides methods for expanding a tubular with the aid of a compressive force. A tubular, such as a string of casing, is run into a wellbore on a working string, e.g., drill pipe. A carrying mechanism such as a collet is used to releasably attach the first tubular to the working string during run-in. The tubular is then expanded into frictional engagement with another tubular therearound within the wellbore. During the expansion process, a compressive force is applied to the portion of the tubular being expanded. In one aspect of the invention, a hydraulic ram is positioned above the string of casing and is activated by the injection of fluid under pressure in order to apply the compressive force to the expandable tubular. In another aspect of the invention, the portion of casing or other expandable tubular to be expanded is pre-stressed, such as to impart a barrel shape, in order to bias the tubular to more easily buckle outwardly during expansion.



US 20030121655A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2003/0121655 A1

Lauritzen et al. (43) Pub. Date: Jul. 3, 2003

(54) THREADED APPARATUS FOR SELECTIVELY TRANSLATING ROTARY EXPANDER TOOL DOWNHOLE

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(73) Assignee: Weatherford/Lamb, Inc.

(21) Appl. No.: 10/034,592

(22) Filed: Dec. 28, 2001

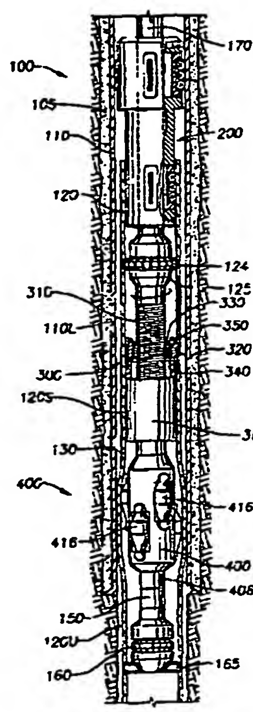
Publication Classification

(51) Int. Cl.^{7} E21B 19/16

(52) U.S. Cl. 166/207; 166/380

(57) ABSTRACT

An apparatus for translating an expander tool within a wellbore. The apparatus enables an expander tool to be moved axially within a wellbore during an expansion operation without raising or lowering the working string during the expansion operation. In one aspect, the apparatus comprises a shaft, a nut member which rides along the shaft when the shaft is rotated, and a recess connected to the nut member for receiving the shaft as the nut member travels axially along the shaft. The expander tool is connected at an end to the nut member such that translation of the nut member along the shaft serves to translate the expander tool axially within the wellbore. In one aspect, the shaft employs helical threads for incrementally advancing the nut member upon rotation of the shaft. In a further aspect, the apparatus includes a nut housing for holding the nut member, and a key member disposed within the circumference of the nut and the nut housing. The key member extends into a spline fabricated into the inner surface of the tubular to be expanded, such as a lower string of casing, to maintain the nut member in a non-rotational manner during rotation of the shaft.



US 20030111234A1

(19) United States
(12) Patent Application Publication
McClurkin et al.
(10) Pub. No.: US 2003/0111234 A1
(43) Pub. Date: Jun. 19, 2003

(54) TECHNIQUE FOR EXPANDING TUBULAR STRUCTURES

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(21) Appl. No.: 10/028,949

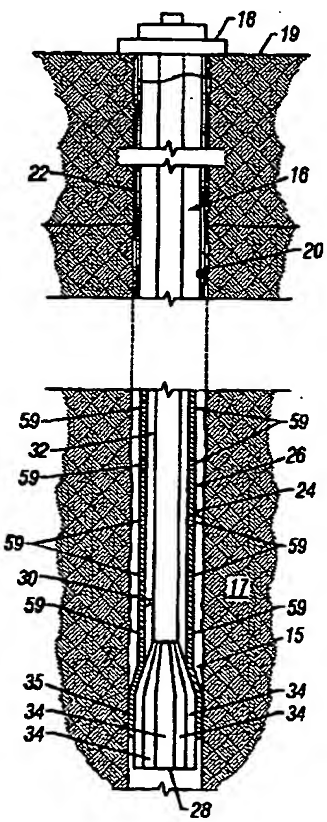
(22) Filed: Dec. 17, 2001

Publication Classification

(51) Int. Cl.[7] E21B 23/00
(52) U.S. Cl. 166/384; 166/207; 166/380

(57) ABSTRACT

A system for expanding tubular structures. The system comprises a mandrel that is moved through the center of a tubular structure to increase the diameter of the tubular structure via deformation. The system utilizes an expansion device having a mandrel with multiple segments moved between a contracted state and an expanded state. In one embodiment, the mandrel segments are spring biased to permit a degree of independent movement of each mandrel segment with respect to the other mandrel segments.



US 20030047322A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0047322 A1
Maguire et al. (43) Pub. Date: Mar. 13, 2003

(54) AN EXPANDABLE HANGER AND PACKER

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(21) Appl. No.: 09/949,986

(22) Filed: Sep. 10, 2001

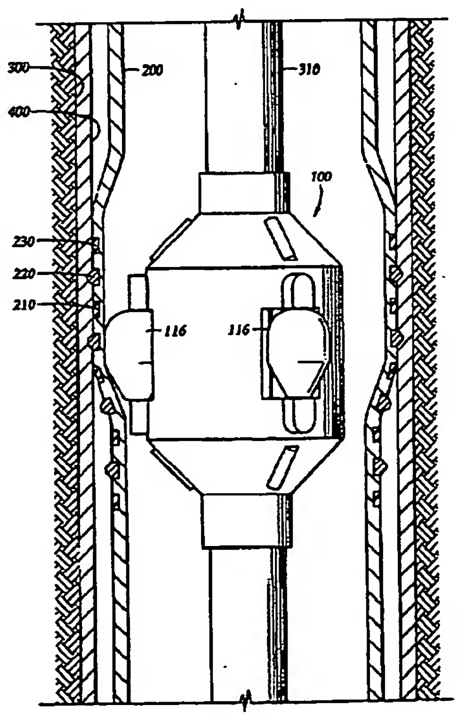
Publication Classification

(51) Int. Cl.[7] E21B 23/02

(52) U.S. Cl. 166/380; 166/207

(57) ABSTRACT

An apparatus and method of creating a seal between two coaxial tubulars so as to create a hanger and a packer. A first tubular is disposed coaxially within a portion of a second, larger tubular. A portion of the first tubular is expanded into frictional contact with the second tubular, thereby creating a liner and a hanger. In one embodiment, a pattern of grooves is formed in the surface of a portion of the first tubular body. The grooves in one aspect define a continuous pattern about the circumference of the tubular body which intersect to form a plurality of substantially identical shapes, such as diamonds. The grooves serve to improve the tensile strength of the tubular body. At the same time, the grooves allow for expansion of the tubular body by use of less radial force. The grooves further provide a gripping means, providing additional frictional support for hanging the expanded tubular onto the inner surface of a surrounding second tubular. The apparatus and method optionally provides a pliable material fabricated within the grooves on the outer surface of the tubular body. In addition, carbide inserts are preferably interdisposed within the pattern of grooves, providing additional gripping means when the smaller diameter tubular body is expanded into the second tubular.



US 20030140673A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0140673 A1
Marr et al. (43) Pub. Date: Jul. 31, 2003

(54) TUBING EXPANSION

(76) Inventors: Graeme Thomas Marr, Inverurie (GB); Mark Davies, Inverurie (GB)

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(21) Appl. No.: 10/324,420

(22) Filed: Dec. 20, 2002

(30) Foreign Application Priority Data

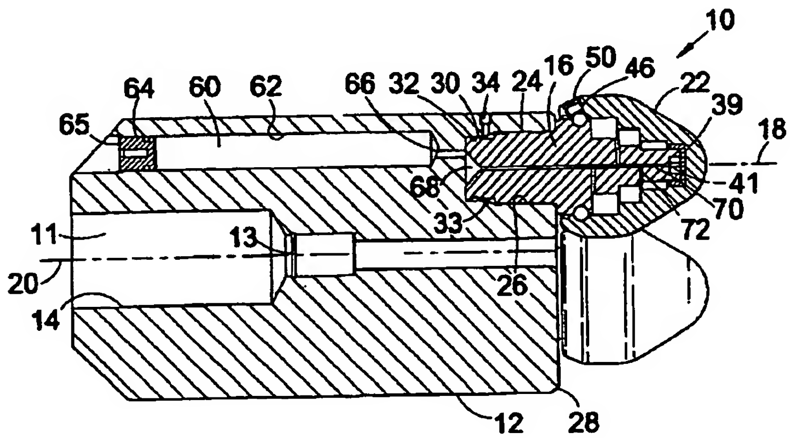
Dec. 22, 2001 (GB) 0130848.5

Publication Classification

(51) Int. Cl.^{7} B21D 39/08
(52) U.S. Cl. 72/58

(57) ABSTRACT

In an embodiment of the invention, there is disclosed a tubing expansion tool (300) comprising a body (302) adapted for rotation within tubing to be expanded, and three expansion member modules (306) each comprising an expansion member (310) rotatably mounted with respect to the body (302), each expansion member module (306) being releasably coupled to the body (302) as a unit.



US 20030116319A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0116319 A1
Brothers et al. (43) Pub. Date: Jun. 26, 2003

(54) METHODS AND COMPOSITIONS FOR SEALING AN EXPANDABLE TUBULAR IN A WELLBORE

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(21) Appl. No.: 10/243,001

(22) Filed: Sep. 13, 2002

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/006,109, filed on Dec. 4, 2001.

Publication Classification

(51) Int. Cl.^{7} E21B 33/13; E21B 33/14
(52) U.S. Cl. 166/287; 166/295; 166/300; 523/130

(57) ABSTRACT

Methods and compositions are provided for sealing an expandable tubular in a wellbore wherein the methods basically comprise placing the expandable tubular in the wellbore, placing a resilient sealing composition into the wellbore, expanding the expandable tubular and allowing the sealing composition to set in the wellbore.

US 20030047323A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2003/0047323 A1
Jackson et al. (43) Pub. Date: Mar. 13, 2003

(54) EXPANDABLE HANGER AND PACKER

(75) Inventors: Stephen L. Jackson, Richmond, TX (US); Patrick Maguire, Cypress, TX (US); Khai Tran, Pearland, TX (US)

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(73) Assignee: Weatherford/Lamb, Inc.

(21) Appl. No.: 10/132,424

(22) Filed: Apr. 25, 2002

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/949,986, filed on Sep. 10, 2001.

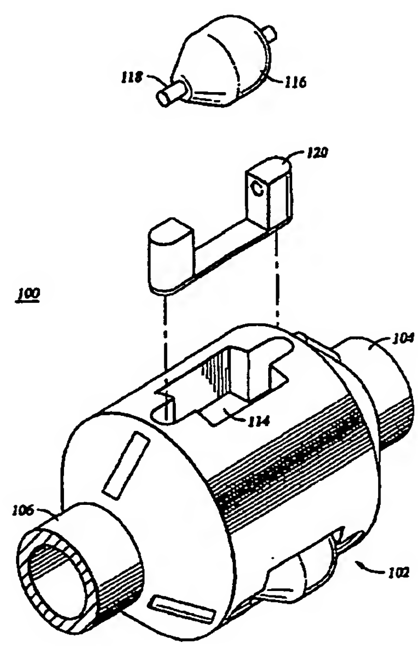
Publication Classification

(51) Int. Cl.^{7} E21B 43/10; E21B 23/02

(52) U.S. Cl. 166/380; 166/277; 166/206

(57) ABSTRACT

An apparatus and method of creating a seal between two coaxial tubulars so as to create a hanger and a packer. A first tubular is disposed coaxially within a portion of a second, larger tubular. A portion of the first tubular is expanded into frictional contact with the second tubular, thereby creating a liner and a hanger. In one embodiment, a pattern of grooves and profile cuts are formed in the surface of a portion of the first tubular body. The grooves in one aspect define a continuous pattern about the circumference of the tubular body which intersect to form a plurality of substantially identical shapes, such as diamonds. The grooves and profile cuts serve to improve the tensile strength of the tubular body. At the same time, the grooves and profile cuts allow for expansion of the tubular body by use of less radial force. The grooves and profile cuts further provide a gripping means, providing additional frictional support for hanging the expanded tubular onto the inner surface of a surrounding second tubular.



US 20020139540A1

(19) United States
(12) Patent Application Publication
Lauritzen
(10) Pub. No.: US 2002/0139540 A1
(43) Pub. Date: Oct. 3, 2002

(54) METHOD AND APPARATUS FOR DOWNHOLE TUBULAR EXPANSION

(75) Inventor: Eric Lauritzen, Kingwood, TX (US)

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(73) Assignee: Weatherford/Lamb, Inc.

(21) Appl. No.: 09/818,119

(22) Filed: Mar. 27, 2001

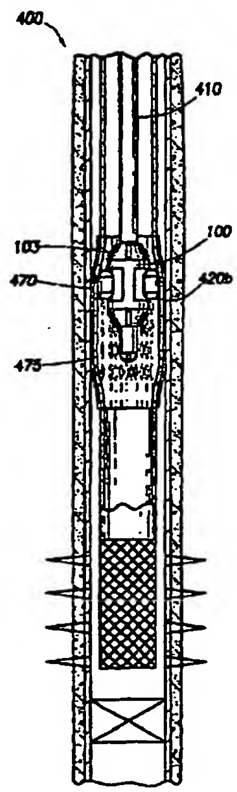
Publication Classification

(51) Int. Cl.^{7} E21B 43/10; E21B 43/12

(52) U.S. Cl. 166/387; 166/277; 166/206

(57) ABSTRACT

The present invention provides apparatus and methods for expanding tubulars in a wellbore. In one aspect, a process of sealing an annular area in a wellbore is provided in which a tubular having perforations at a predetermined location and a sleeve concentrically covering substantially all of the perforations is expanded into substantial contact with an inner diameter of a tubular, such as a casing or a liner. In another aspect, a process of sealing an annular area in a wellbore is provided in which a tubular having perforation at a predetermined location and a sleeve concentrically coving substantially all of the perforations is expanded into substantial contact with a junction between two tubulars, such as a liner and a casing, or between two liners.



US 20020100594A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2002/0100594 A1

Cook et al. (43) Pub. Date: Aug. 1, 2002

(54) WELLBORE CASING

(75) Inventors: Robert Lance Cook, Katy, TX (US); David Paul Brisco, Duncan, OK (US); Lev Ring, Houston, TX (US); Michael Bullock, The Woodlands, TX (US)

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(73) Assignee: Shell Oil Co.

(21) Appl. No.: 10/074,703

(22) Filed: Feb. 12, 2002

Related U.S. Application Data

(62) Division of application No. 09/512,895, filed on Feb. 24, 2000.

(60) Provisional application No. 60/121,841, filed on Feb. 26, 1999. Provisional application No. 60/154,047, filed on Sep. 16, 1999.

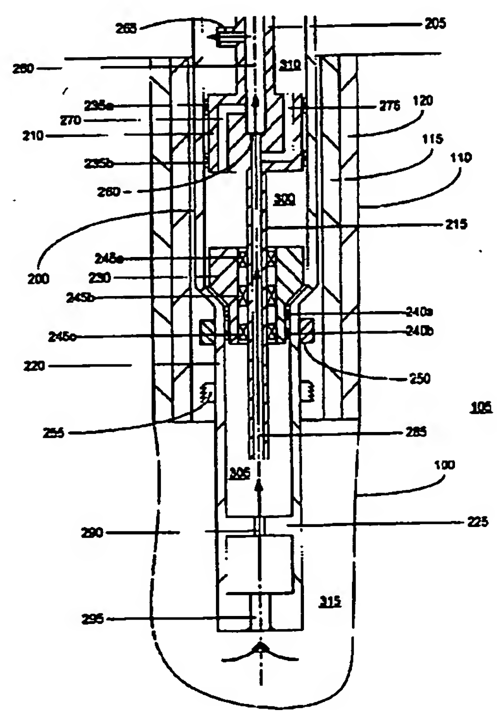
Publication Classification

(51) Int. Cl.^{7} E21B 23/00

(52) U.S. Cl. 166/380; 166/382; 166/212; 166/208; 166/242.6

(57) ABSTRACT

An apparatus and method for forming a wellbore casing. An annular piston is displaced in the axial direction by pressurizing an annular piston chamber. The axial displacement of the piston radially expands a tubular member into contact with a preexisting tubular member. The radially expanded liner hanger is then decoupled from the apparatus.



US 20020092657A1

(19) United States
(12) Patent Application Publication
Cook et al.
(10) Pub. No.: US 2002/0092657 A1
(43) Pub. Date: Jul. 18, 2002

(54) METHOD OF APPLYING AN AXIAL FORCE TO AN EXPANSION CONE

(75) Inventors: Robert Lance Cook, Katy, TX (US); David Paul Brisco, Duncan, OK (US); Lev Ring, Houston, TX (US); Michael Bullock, The Woodlands, TX (US)

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(73) Assignee: Shell Oil Co.

(21) Appl. No.: 10/076,659

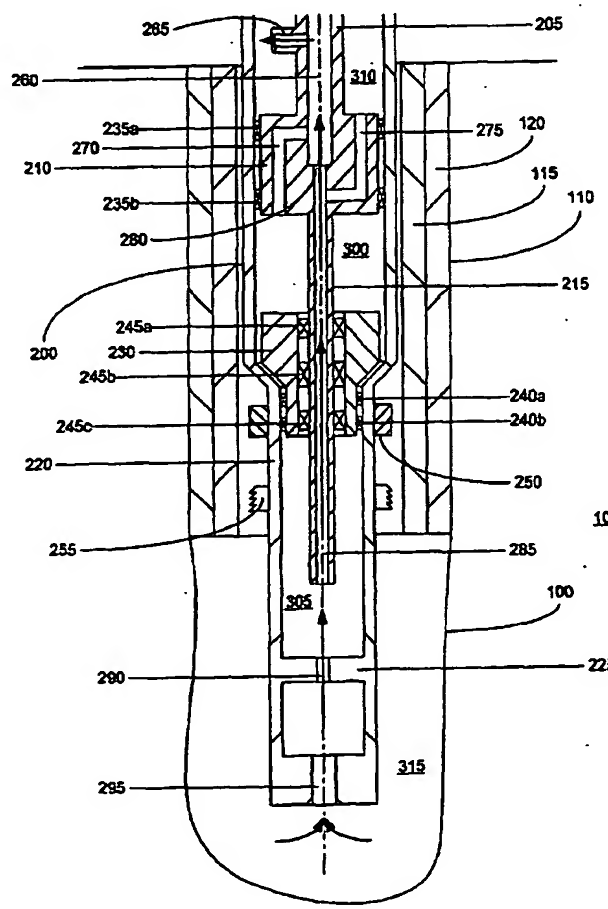
(22) Filed: Feb. 15, 2002

Publication Classification

(51) Int. Cl.[7] E21B 23/04; E21B 43/10
(52) U.S. Cl. 166/382; 166/212; 166/208; 166/207; 166/242.6

(57) ABSTRACT

A method of applying an axial force to an expansion cone.



US 20020079100A1

(19) **United States**
(12) **Patent Application Publication** (10) Pub. No.: US 2002/0079100 A1
Simpson et al. (43) Pub. Date: Jun. 27, 2002

(54) APPARATUS, METHODS, AND APPLICATIONS FOR EXPANDING TUBULARS IN A WELLBORE

(76) Inventors: Neil A.A. Simpson, Aberdeen (GB); Mark Hopmann, Alvin, TX (US)

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(21) Appl. No.: 09/990,092

(22) Filed: Nov. 21, 2001

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/828,508, filed on Apr. 6, 2001, which is a continuation of application No. 09/469,690, filed on Dec. 22, 1999.

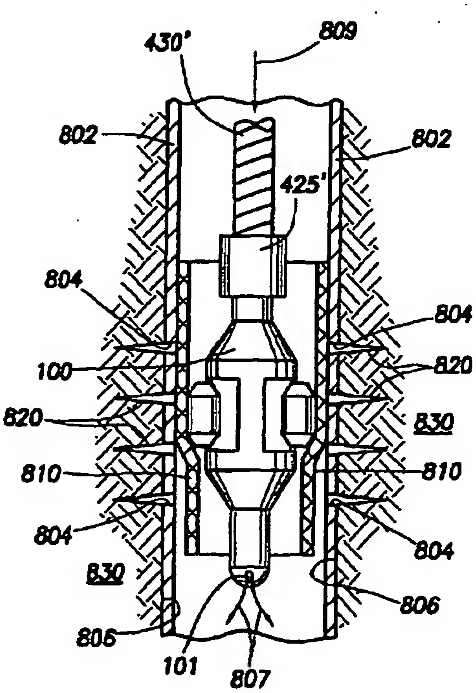
Publication Classification

(51) Int. Cl.^{7} E21B 43/08; E21B 23/00

(52) U.S. Cl. 166/278; 166/384; 166/227; 166/206

(57) ABSTRACT

The present invention relates to methods and apparatus for expanding tubulars in a wellbore. In one aspect of the invention, an expansion tool with hydraulically actuated, radially expandable members is disposed on a string of coil tubing. In another aspect of the invention the apparatus is utilized to expand a tubular lining a lateral wellbore into contact with a window of a larger tubular lining a central wellbore. The tubular lining can comprise nonporous or porous material.



US 20020074134A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2002/0074134 A1

Cook et al. (43) Pub. Date: Jun. 20, 2002

(54) APPARATUS FOR ACTUATING AN ANNULAR PISTON

(75) Inventors: Robert Lance Cook, Katy, TX (US); David Paul Brisco, Duncan, OK (US); Lev Ring, Houston, TX (US); Michael Bullock, The Woodlands, TX (US)

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(73) Assignee: Shell Oil Co.

(21) Appl. No.: 10/078,922

(22) Filed: Feb. 20, 2002

Related U.S. Application Data

(60) Division of application No. 09/512,895, filed on Feb. 24, 2000, which is a non-provisional of provisional application No. 60/121,841, filed on Feb. 26, 1999 and which is a non-provisional of provisional application No. 60/154,047, filed on Sep. 16, 1999.

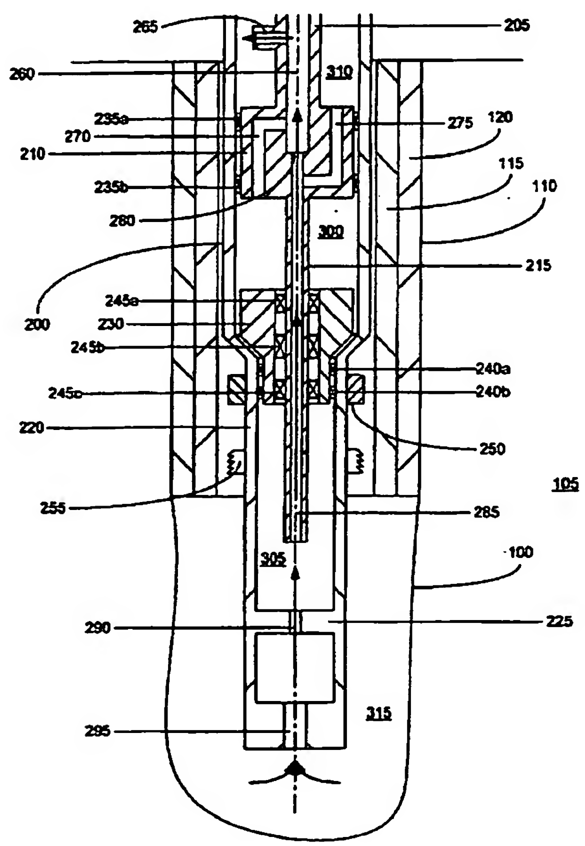
Publication Classification

(51) Int. Cl.[7] E21B 23/00

(52) U.S. Cl. 166/383; 166/384; 166/380; 166/207

(57) ABSTRACT

An apparatus for actuating an annular piston.



US 20020185274A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2002/0185274 A1
Simpson et al. (43) Pub. Date: Dec. 12, 2002

(54) APPARATUS AND METHODS FOR EXPANDING TUBULARS IN A WELLBORE

(75) Inventors: Neil A.A. Simpson, Aberdeen (GB); David Haugen, League City, TX (US)

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(73) Assignee: Weatherford/Lamb, Inc.

(21) Appl. No.: 10/212,304

(22) Filed: Aug. 5, 2002

Related U.S. Application Data

(60) Division of application No. 09/828,508, filed on Apr. 6, 2001, and which is a continuation-in-part of application No. 09/469,692, filed on Dec. 22, 1999, now Pat. No. 6,325,148, and which is a continuation-in-part of application No. 09/469,690, filed on Dec. 22, 1999, now Pat. No. 6,457,532.

(60) Provisional application No. 60/202,335, filed on May 5, 2000.

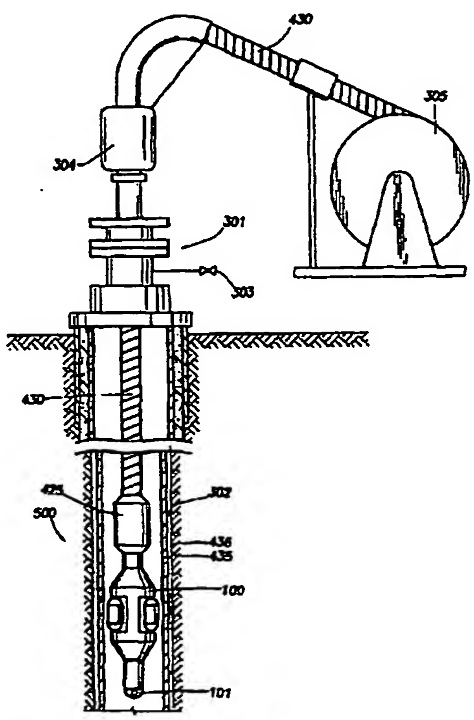
Publication Classification

(51) Int. Cl.^{7} E21B 23/04; E21B 29/00; E21B 19/00

(52) U.S. Cl. 166/277; 166/384; 166/217

(57) ABSTRACT

The present invention relates to methods and apparatus for expanding tubulars in a wellbore. In one aspect of the invention, an expansion tool with hydraulically actuated, radially expandable members is disposed on a string of coil tubing. In another aspect of the invention the apparatus is utilized to expand a tubular lining a lateral wellbore into contact with a window of a larger tubular lining a central wellbore.



US 20020100593A1

(19) United States
(12) Patent Application Publication
Cook et al.
(10) Pub. No.: US 2002/0100593 A1
(43) Pub. Date: Aug. 1, 2002

(54) PRELOAD FOR EXPANSION CONE

(75) Inventors: Robert Lance Cook, Katy, TX (US); David Paul Brisco, Duncan, OK (US); Lev Ring, Houston, TX (US); Michael Bullock, The Woodlands, TX (US)

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(73) Assignee: Shell Oil Co.

(21) Appl. No.: 10/074,244

(22) Filed: Feb. 12, 2002

Related U.S. Application Data

(62) Division of application No. 09/512,895, filed on Feb. 24, 2000.

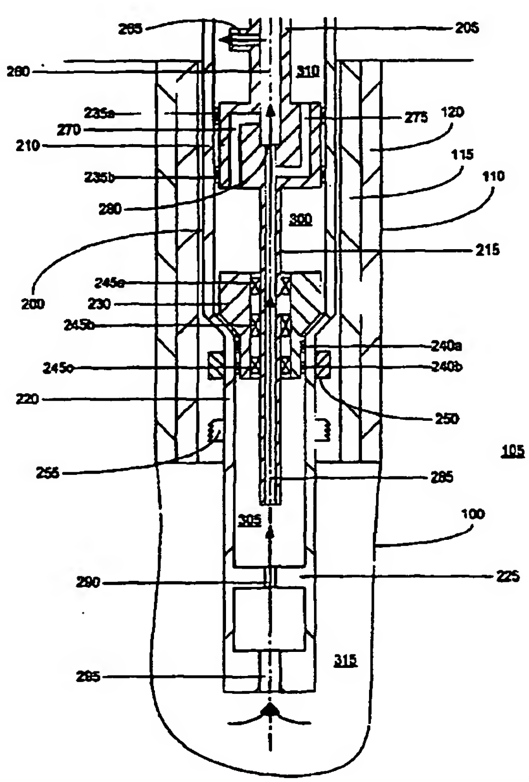
(60) Provisional application No. 60/121,841, filed on Feb. 26, 1999. Provisional application No. 60/154,047, filed on Sep. 16, 1999.

Publication Classification

(51) Int. Cl.[7] E21B 19/16
(52) U.S. Cl. 166/380; 166/207; 166/383; 166/242.6

(57) ABSTRACT

An apparatus for applying a preload force to an expansion cone for radially expanding a tubular member.



US 20010045284A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2001/0045284 A1
Simpson et al. (43) Pub. Date: Nov. 29, 2001

(54) APPARATUS AND METHODS FOR EXPANDING TUBULARS IN A WELLBORE

(75) Inventors: Neil A.A. Simpson, Aberdeen (GB); David Haugen, League City, TX (US)

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Houston, TX 77056 (US)

(73) Assignee: Weatherford/Lamb, Inc.

(21) Appl. No.: 09/828,508

(22) Filed: Apr. 6, 2001

Related U.S. Application Data

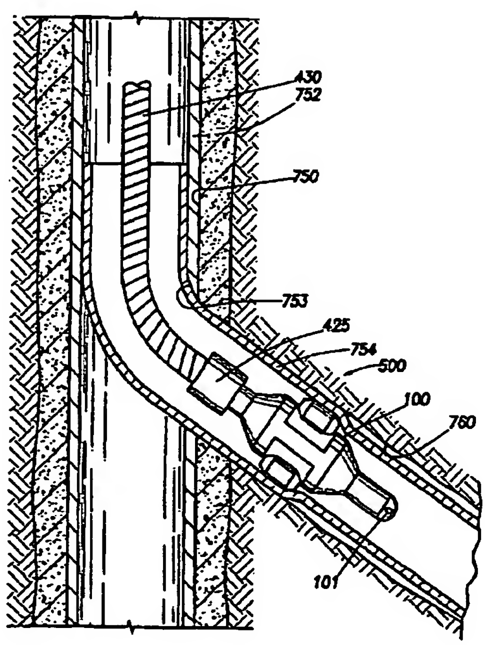
(63) Non-provisional of provisional application No. 60/202,355, filed on May 5, 2000. Continuation-in-part of application No. 09/469,692, filed on Dec. 22, 1999. Continuation-in-part of application No. 09/469,690, filed on Dec. 22, 1999.

Publication Classification

(51) Int. Cl.[7] E21B 43/00; E21B 43/10
(52) U.S. Cl. 166/313; 166/50; 166/207

(57) ABSTRACT

The present invention relates to methods and apparatus for expanding tubulars in a wellbore. In one aspect of the invention, an expansion tool with hydraulically actuated, radially expandable members is disposed on a string of coil tubing. In another aspect of the invention the apparatus is utilized to expand a tubular lining a lateral wellbore into contact with a window of a larger tubular lining a central wellbore.



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US006334351B1

(12) **United States Patent**
Tsuchiya

(10) **Patent No.: US 6,334,351 B1**
(45) **Date of Patent: Jan. 1, 2002**

(54) **METAL PIPE EXPANDER**

(75) Inventor: **Masaki Tsuchiya**, Yokkaichi (JP)

(73) Assignee: **Daido Tokushuko Kabushiki Kaisha**, Aichi (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/706,712**

(22) Filed: **Nov. 7, 2000**

(30) **Foreign Application Priority Data**

Nov. 8, 1999 (JP) 11-316201

(51) **Int. Cl.**[7] **B21D 3/14; B21B 17/06**
(52) **U.S. Cl.** **72/370.06; 29/402.01**
(58) **Field of Search** 72/75, 370.01, 72/370.06, 453.1, 479; 29/402.01

(56) **References Cited**

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4,005,591 A * 2/1977 Werner 72/75

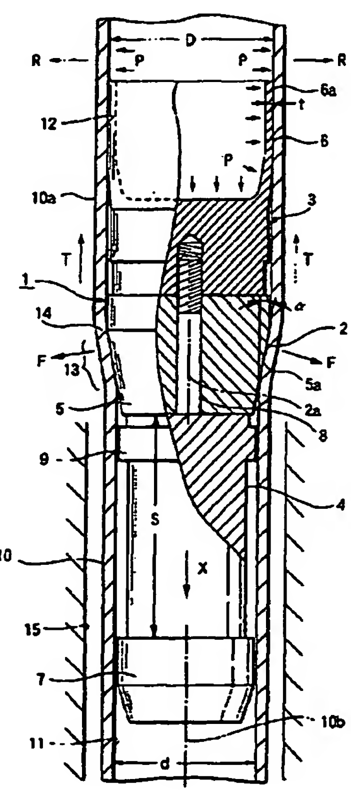
* cited by examiner

Primary Examiner—David Jones
(74) *Attorney, Agent, or Firm*—Bacon & Thomas, PLLC

(57) **ABSTRACT**

A metal pipe expander which is inserted into a metal pipe and driven to move in the axial direction of the metal pipe by a liquid pressure has an expanding section and a pressure receiving section. The expanding section has a conical portion of which a small diameter portion is directed to a front side. The pressure receiving section has a cup shaped portion opened to the rear side, the outer surface of which is in slide contact with an inner surface of the metal pipe after it is expanded in diameter. The pressure receiving section is provided at a rear end of an expanding section.

10 Claims, 4 Drawing Sheets



US006470966B2

(12) **United States Patent**
Cook et al.

(10) Patent No.: **US 6,470,966 B2**
(45) Date of Patent: **Oct. 29, 2002**

(54) APPARATUS FOR FORMING WELLBORE CASING

(76) Inventors: Robert Lance Cook, 934 Caswell Ct., Katy, TX (US) 77450; David Paul Brisco, 405 Westridge Dr., Duncan, OK (US) 73533; R. Bruce Stewart, Wassenaarseweg 208, 2596 EC, The Hague (NL); Lev Ring, 14126 Heatherhill Pl., Houston, TX (US) 77077; Richard Carl Haut, 502 Lakebend Dr., Sugar Land, TX (US) 77479-5831; Robert Donald Mack, 22435 Vobe Ct., Katy, TX (US) 77449

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: 09/850,093

(22) Filed: May 7, 2001

(65) Prior Publication Data

US 2001/0047870 A1 Dec. 6, 2001

Related U.S. Application Data

(62) Division of application No. 09/454,139, filed on Dec. 3, 1999.

(60) Provisional application No. 60/111,293, filed on Dec. 7, 1998.

(51) Int. Cl.7 .... E21B 23/00; E21B 43/10

(52) U.S. Cl. 166/207; 166/380; 166/212

(58) Field of Search 166/85.1, 177.4, 166/207, 212, 216, 211, 242.1, 375, 380

(56) References Cited

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International Search Report, Application No. PCT/US00/30022, Oct. 31, 2000.

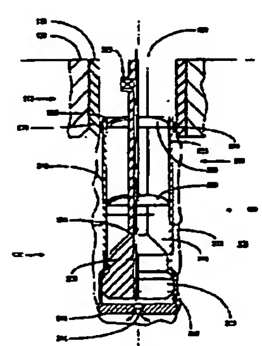
International Search Report, Application No. PCT/US01/19014, Jun. 12, 2001.

Primary Examiner—David Bagnell
Assistant Examiner—Jennifer R Dougherty
(74) *Attorney, Agent, or Firm*—Todd Mattingly; Haynes & Boone L.L.P.

(57) ABSTRACT

A wellbore casing formed by extruding a tubular liner off of a mandrel. The tubular liner and mandrel are positioned within a new section of a wellbore with the tubular liner in an overlapping relationship with an existing casing. A hardenable fluidic material is injected into the new section of the wellbore below the level of the mandrel and into the annular region between the tubular liner and the new section of the wellbore. The inner and outer regions of the tubular liner are then fluidicly isolated. A non hardenable fluidic material is then injected into a portion of an interior region of the tubular liner to pressurize the portion of the interior region of the tubular liner below the mandrel. The tubular liner is then extruded off of the mandrel.

36 Claims, 26 Drawing Sheets



US006543552B1

(12) **United States Patent**
Metcalfe et al.

(10) Patent No.: **US 6,543,552 B1**
(45) Date of Patent: **Apr. 8, 2003**

(54) **METHOD AND APPARATUS FOR DRILLING AND LINING A WELLBORE**

(75) Inventors: **Paul David Metcalfe**, Peterculter (GB); **Neil Andrew Abercrombie Simpson**, Aberdeen (GB)

(73) Assignee: **Weatherford/Lamb, Inc.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/469,643**

(22) Filed: **Dec. 22, 1999**

(30) **Foreign Application Priority Data**

Dec. 22, 1998 (GB) 9828234
Jan. 15, 1999 (GB) 9900835
Oct. 8, 1999 (GB) 9923783
Oct. 13, 1999 (GB) 9924189

(51) Int. Cl.[7] **E21B 7/00**; E21B 7/20; E21B 23/00; B21D 41/02

(52) U.S. Cl. 175/57; 175/171; 175/258; 166/208; 166/212; 166/277; 166/382; 72/393

(58) Field of Search 72/97, 150, 148, 72/393, 75; 166/277, 382, 206, 384, 207, 208, 212, 217, 98; 175/23, 57, 171, 258

(56) **References Cited**

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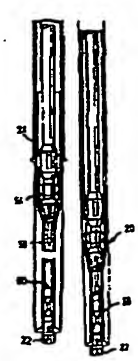
(List continued on next page.)

Primary Examiner—David Bagnell
Assistant Examiner—Jennifer H Gay
(74) *Attorney, Agent, or Firm*—Moser, Patterson & Sheridan, L.L.P.

(57) **ABSTRACT**

A method and apparatus is provided for drilling and lining a wellbore in one downhole trip. The method comprises mounting a drill bit on a drill string including a section of expandable tubing and providing a tubing expander in the string, then rotating the drill bit and advancing the drill string through a bore, then passing the expander through the expandable tubing to expand the tubing, wherein the expandable tubing is deformed by compressive plastic deformation of the tubing with a localised reduction in wall thickness, resulting in a subsequent increase in tubing diameter, and then retrieving the drill bit from the bore through the expanded tubing. The apparatus comprises a drill string including a section of expandable tubing, a drill bit mounted on the string, and a tubing expander mounted on the string, wherein the expandable tubing is deformed by compressive plastic deformation of the tubing with a localised reduction in wall thickness, resulting in a subsequent increase in tubing diameter and wherein the drill bit may be retrieved through the expanded tubing.

22 Claims, 3 Drawing Sheets



US006557640B1

(12) **United States Patent**
Cook et al.

(10) Patent No.: **US 6,557,640 B1**
(45) Date of Patent: **May 6, 2003**

(54) LUBRICATION AND SELF-CLEANING SYSTEM FOR EXPANSION MANDREL

(75) Inventors: Robert Lance Cook, Katy, TX (US); David Paul Brisco, Duncan, OK (US); R. Bruce Stewart, The Hague (NL); Reece E. Wyant, Houston, TX (US); Lev Ring, Houston, TX (US); James Jang Woo Nahm, Fullbrock, CA (US); Richard Carl Haut, Sugar Land, TX (US); Robert Donald Mack, Katy, TX (US); Alan B. Duell, Duncan, OK (US); Andrei Gregory Filippov, Katy, TX (US)

(73) Assignee: Shell Oil Company, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: 09/588,946

(22) Filed: Jun. 7, 2000

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/559,122, filed on Apr. 26, 2000, which is a continuation-in-part of application No. 09/523,460, filed on Mar. 10, 2000, which is a continuation-in-part of application No. 09/510,913, filed on Feb. 23, 2000, which is a continuation-in-part of application No. 09/502,350, filed on Feb. 10, 2000, which is a continuation-in-part of application No. 09/454,139, filed on Dec. 3, 1999.

(60) Provisional application No. 60/131,106, filed on Apr. 26, 1999, provisional application No. 60/124,042, filed on Mar. 11, 1999, provisional application No. 60/121,702, filed on Feb. 25, 1999, provisional application No. 60/119,611, filed on Feb. 11, 1999, and provisional application No. 60/111,293, filed on Dec. 7, 1998.

(51) Int. Cl.^{7} E21B 43/10

(52) U.S. Cl. 166/380; 166/207; 166/242.1

(58) Field of Search 166/85.1, 177.4, 166/207, 212, 216, 217, 242.1, 378, 380

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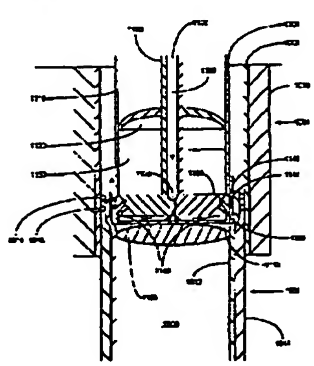
Primary Examiner—David Bagnell
Assistant Examiner—Jennifer R. Dougherty
(74) *Attorney, Agent, or Firm*—Todd Mattingly; Haynes and Boone L.L.P.

(57) ABSTRACT

An expansion mandrel includes a lubrication system for lubricating the trailing edge portion of the interface between the expansion mandrel and a tubular member during the radial expansion of the tubular member.

52 Claims, 75 Drawing Sheets



US005101653A

United States Patent [19]

Hermes et al.

[11] Patent Number: 5,101,653

[45] Date of Patent: Apr. 7, 1992

[54] MECHANICAL PIPE EXPANDER

[75] Inventors: Rolf Hermes, Mönchengladbach; Herbert Jansen, Korschenbroich; Hans G. Schiffers; Arno Topfith, both of Mönchengladbach, all of Fed. Rep. of Germany

[73] Assignee: Mannesmann Aktiengesellschaft, Dusseldorf, Fed. Rep. of Germany

[21] Appl. No.: 617,901

[22] Filed: Nov. 26, 1990

[30] Foreign Application Priority Data

Nov. 24, 1989 [DE] Fed. Rep. of Germany 3939356

[51] Int. Cl.[5] B21D 41/02

[52] U.S. Cl. 72/393

[58] Field of Search 72/393

[56] References Cited

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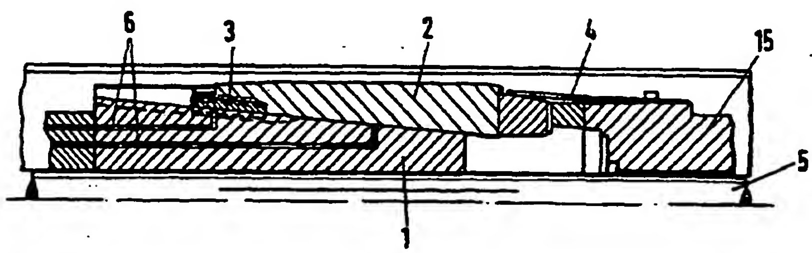
Primary Examiner—Lowell A. Larson

Attorney, Agent, or Firm—Cohen, Pontani & Lieberman

[57] ABSTRACT

A mechanical pipe expander having a pyramidal, polyhedronal cross-section, segments resting against the pyramidal surfaces which are displaceable in axial direction relative to the polyhedron, and grooves formed in the longitudinal centers of the edges of the polyhedron so that the side surfaces of the grooves represent guides for the correspondingly shaped segments. The segments are formed as dove tails on the leading end thereof over a length of about 5-30% of their total length and each of the side surfaces of the dove tail recesses slide on a side surface of two adjacent grooves formed in the polyhedron. The length of the grooves is limited to the path of displacement of the polyhedron with respect to the segments, and the ends of the segments facing away from the leading end are held by radially acting springs against the surfaces of the polyhedron.

6 Claims, 2 Drawing Sheets



AC

US006568471B1

(12) **United States Patent**
Cook et al.

(10) Patent No.: **US 6,568,471 B1**
(45) Date of Patent: **May 27, 2003**

(54) **LINER HANGER**

(75) Inventors: **Robert Lance Cook**, Katy, TX (US); **David Paul Brisco**, Duncan, OK (US); **Lev Ring**, Houston, TX (US); **Michael Bullock**, The Woodlands, TX (US)

(73) Assignee: **Shell Oil Company**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/512,895**

(22) Filed: **Feb. 24, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/154,047, filed on Sep. 16, 1999, and provisional application No. 60/121,841, filed on Feb. 26, 1999.

(51) Int. Cl.[7] E21B 43/08
(52) U.S. Cl. 166/177.4; 166/207
(58) Field of Search 166/85.1, 177.4, 166/207, 212, 216, 211, 242.1, 378, 380

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CA	771462	11/1967	.... 166/16
CA	1171310	7/1984	.... F16B/13/06

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Search Report to Application No. GB 0005399.1, Claims Searched 25–29, Feb. 15, 2001.

Search Report to Application No. GB 9930398.4, Claims Searched 1–35, Jun. 27, 2000.

International Search Report, Application No. PCT/US00/30022, Oct. 31, 2000.

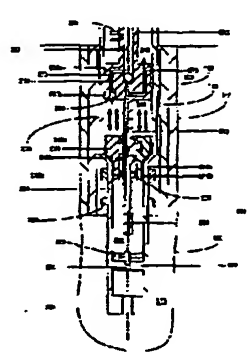
International Search Report, Application No. PCT/US01/19014, Jun. 12, 2001.

Primary Examiner—William Neuder
Assistant Examiner—Jennifer Dougherty
(74) *Attorney, Agent, or Firm*—Haynes and Boone LLP; Todd Mattingly

(57) **ABSTRACT**

An apparatus and method for forming a wellbore casing. An annular piston is displaced in the axial direction by pressurizing an annular piston chamber. The axial displacement of the piston radially expands a tubular member into contact with a preexisting tubular member. The radially expanded liner hanger is then decoupled from the apparatus.

22 Claims, 79 Drawing Sheets



US006578630B2

(12) **United States Patent**
Simpson et al.

(10) Patent No.: **US 6,578,630 B2**
(45) Date of Patent: ***Jun. 17, 2003**

(54) **APPARATUS AND METHODS FOR EXPANDING TUBULARS IN A WELLBORE**

(75) Inventors: Neil A. A. Simpson, Aberdeen (GB); David Haugen, League City, TX (US)

(73) Assignee: Weatherford/Lamb, Inc., Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 33 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: 09/828,508

(22) Filed: Apr. 6, 2001

(65) **Prior Publication Data**

US 2001/0045284 A1 Nov. 29, 2001

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/469,690, filed on Dec. 22, 1999, and a continuation-in-part of application No. 09/469,692, filed on Dec. 22, 1999.

(60) Provisional application No. 60/202,335, filed on May 5, 2000.

(51) Int. Cl.^{7} E21B 23/02

(52) U.S. Cl. 166/55.8; 166/207; 72/119; 72/393

(58) Field of Search 166/55.8, 206, 166/207, 212; 72/75, 118, 119, 393

(56) **References Cited**

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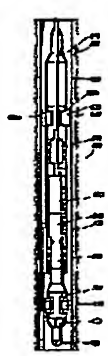
Primary Examiner—William Neuder
(74) *Attorney, Agent, or Firm*—Moser, Patterson & Sheridan, L.L.P.

(57) **ABSTRACT**

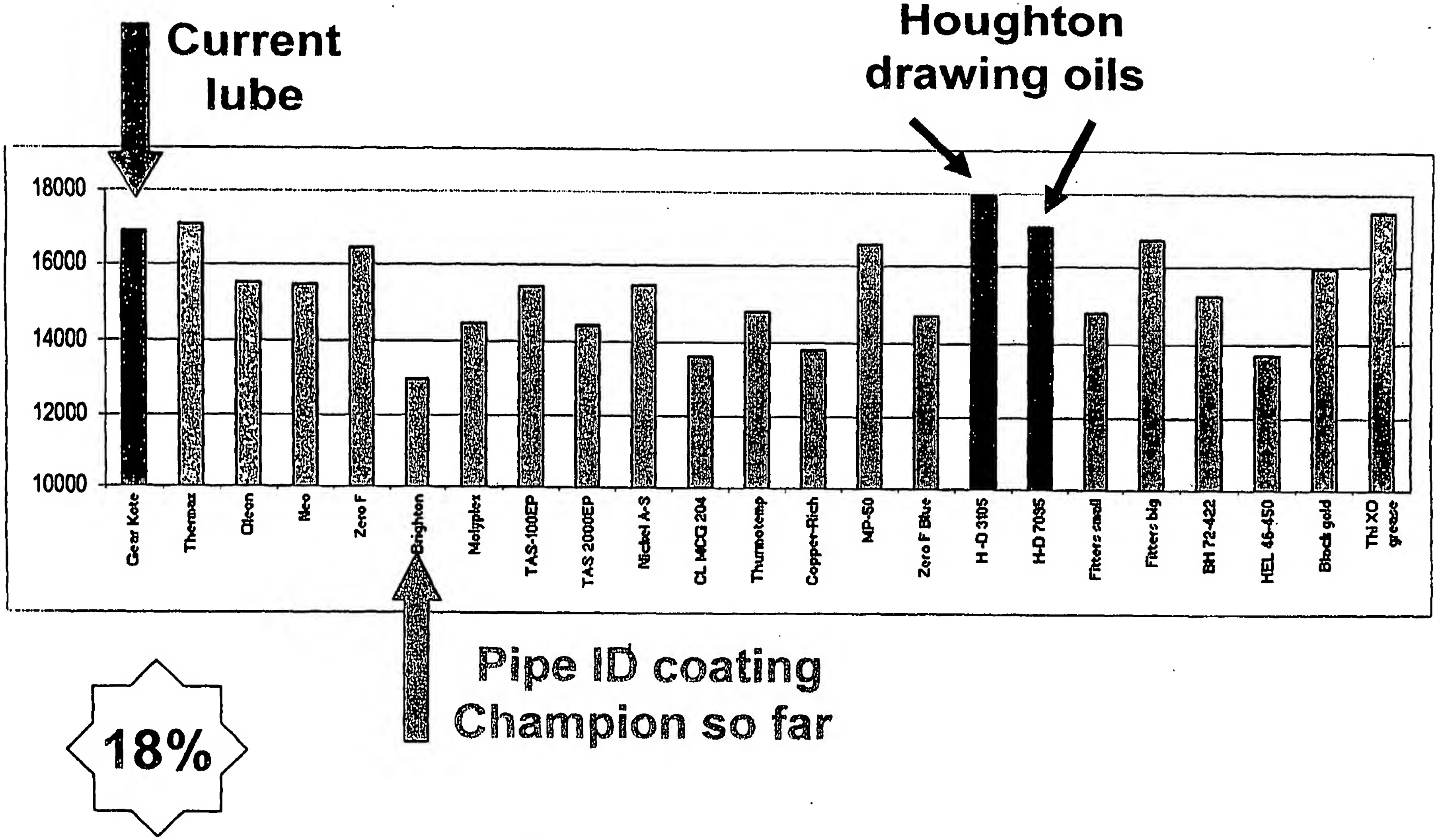
The present invention relates to methods and apparatus for expanding tubulars in a wellbore. In one aspect of the invention, an expansion tool with hydraulically actuated, radially expandable members is disposed on a string of coil tubing. In another aspect of the invention the apparatus is utilized to expand a tubular lining a lateral wellbore into contact with a window of a larger tubular lining a central wellbore.

13 Claims, 6 Drawing Sheets



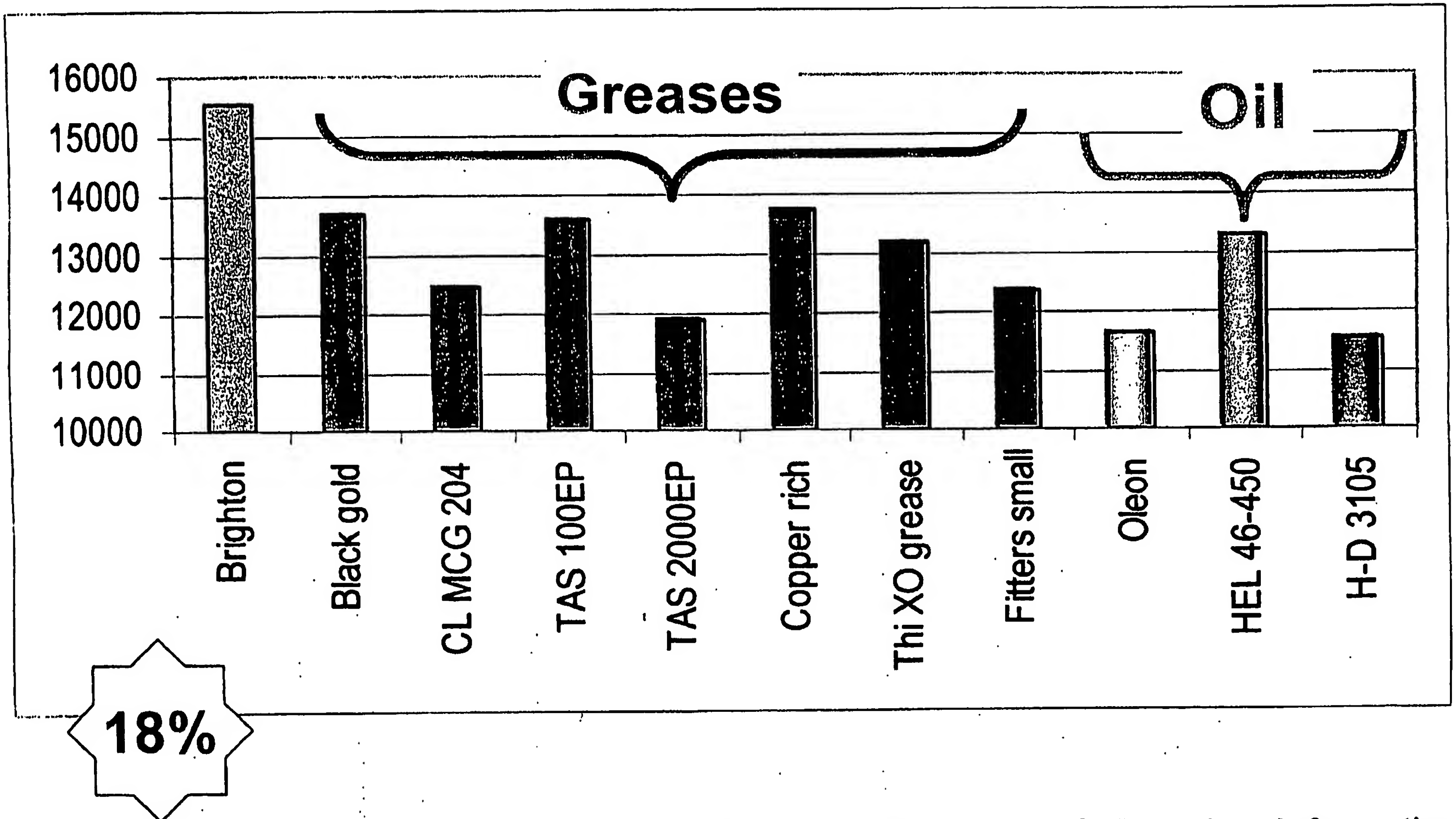
9.2 EGT Lubricant Results

Maximum Forces during Mechanical Expansion of the 1 5/8 "Carbon Steel Pipe with the Best Greases



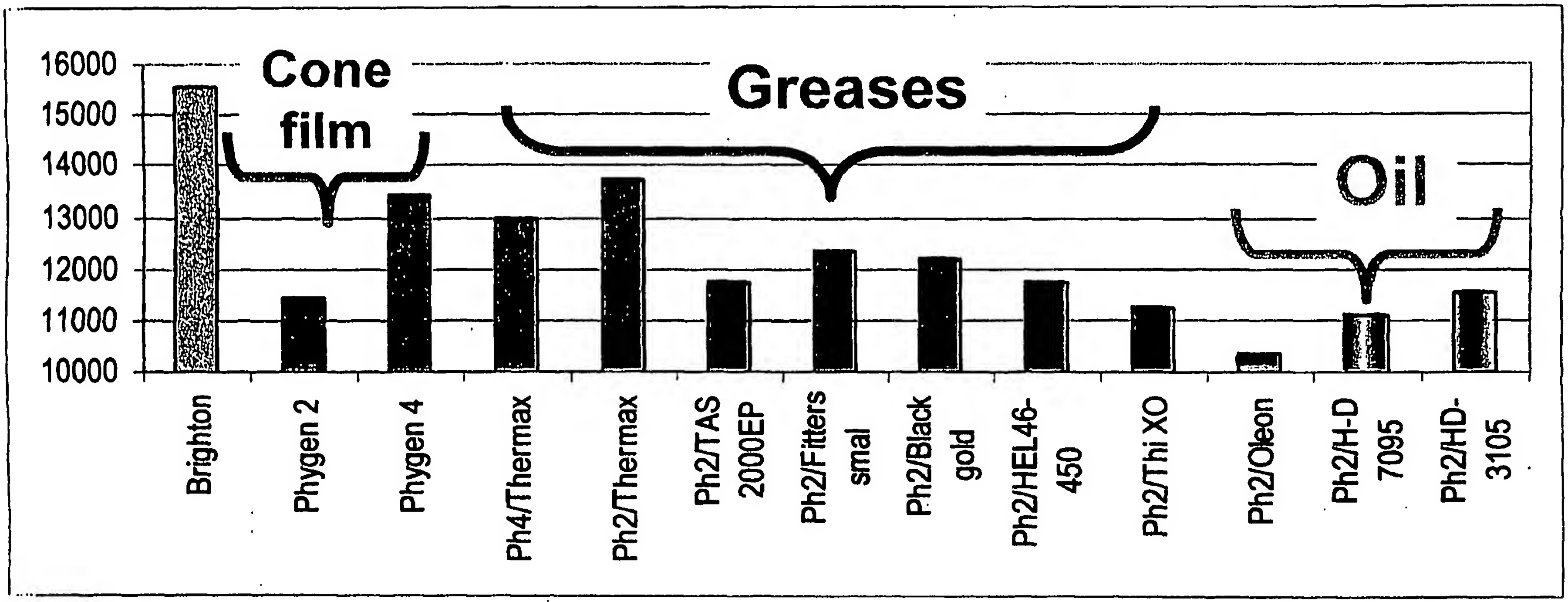
Enventure Global Technology LLC. Propriety Information

*Max Forces during Mechanical Expansion of 1 5/8 "Carbon Steel Pipe Coated by **Brighton** film and additional with Different Lubricants*



Enventure Global Technology LLC. Propriety Information

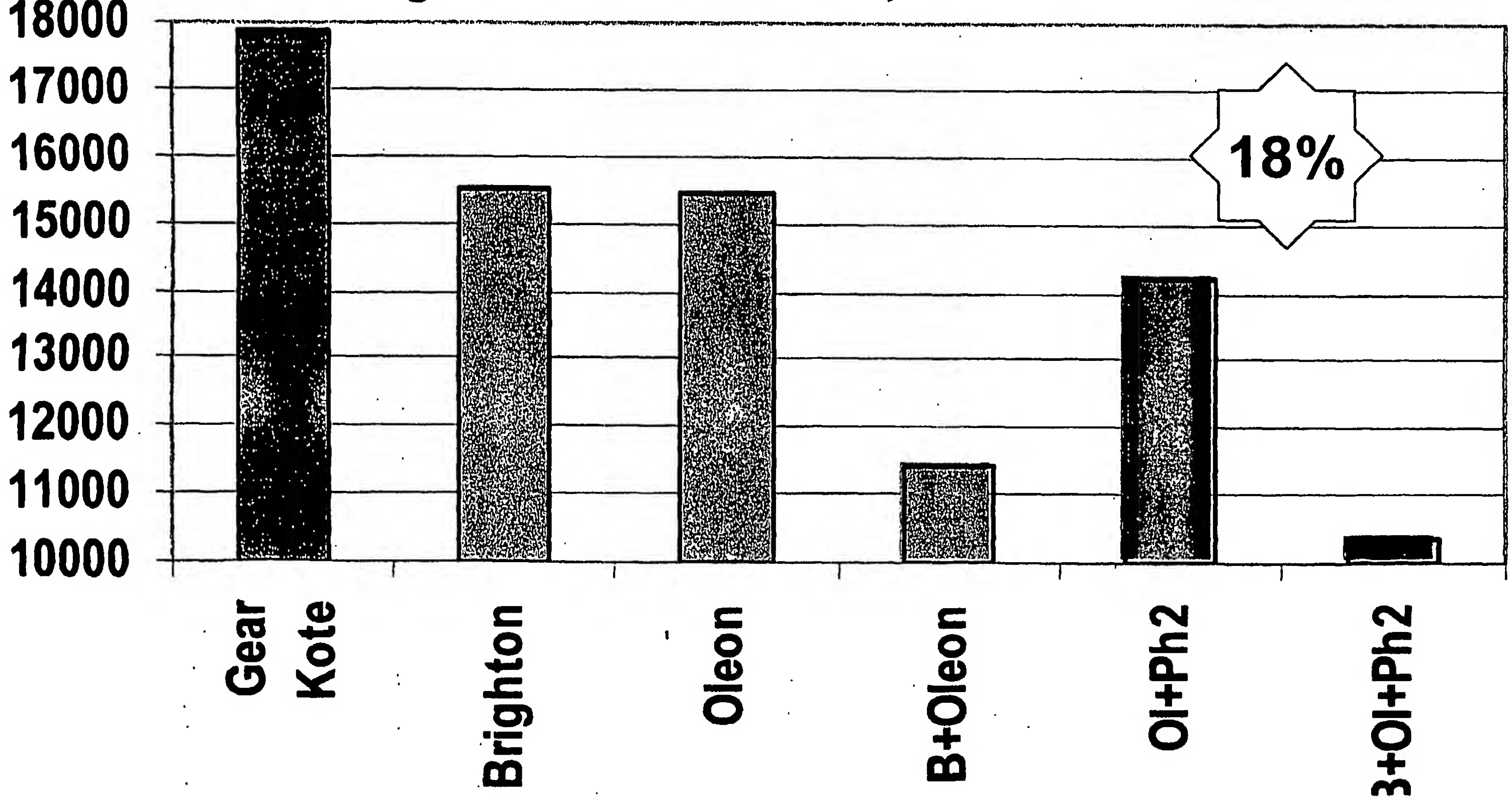
*Max Forces during Mechanical Expansion 1 5/8 "Carbon Steel Pipe Coated by **Brighton** Coating, Cone films and Different Grease Applications*



18%

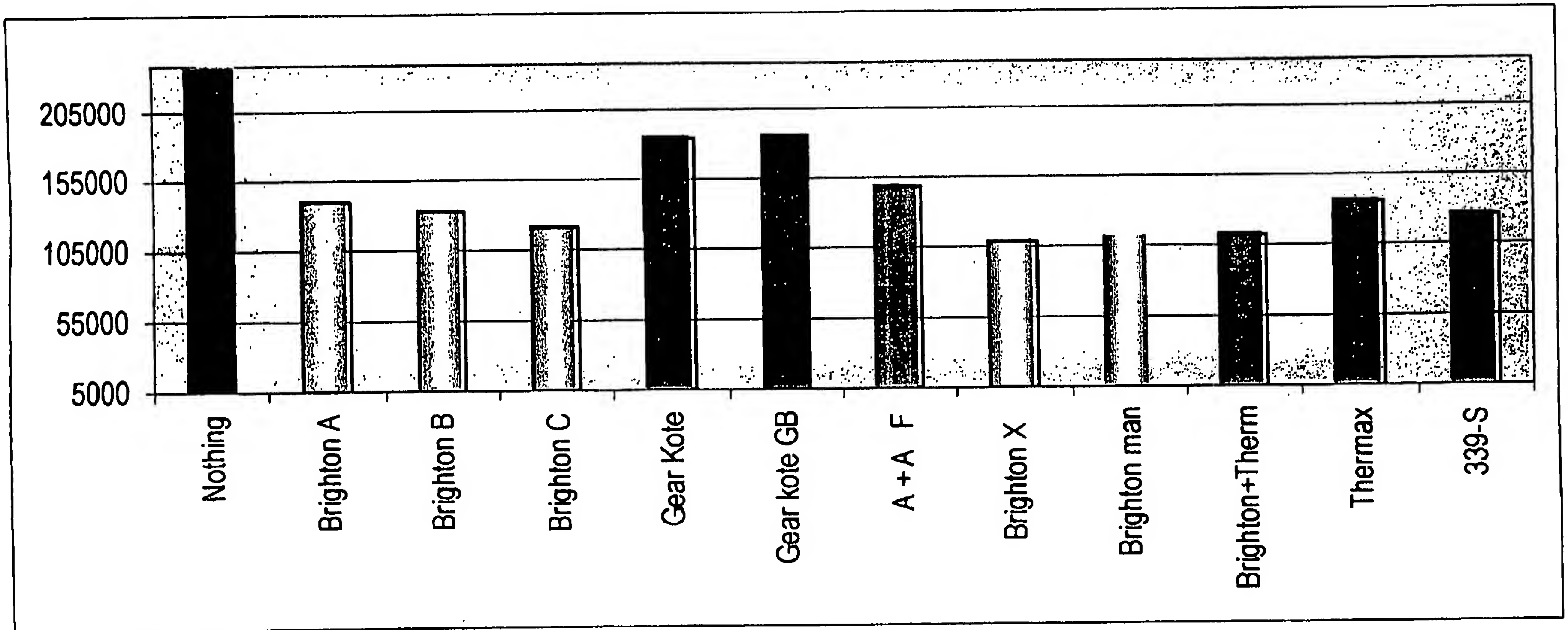
Enventure Global Technology LLC. Propriety Information

Maximum Forces during Mechanical Expansion of the 1 5/8 "Carbon Steel Pipe with the Brighton Pipe ID Coating, Cone Hard Film, and Oleon Oil



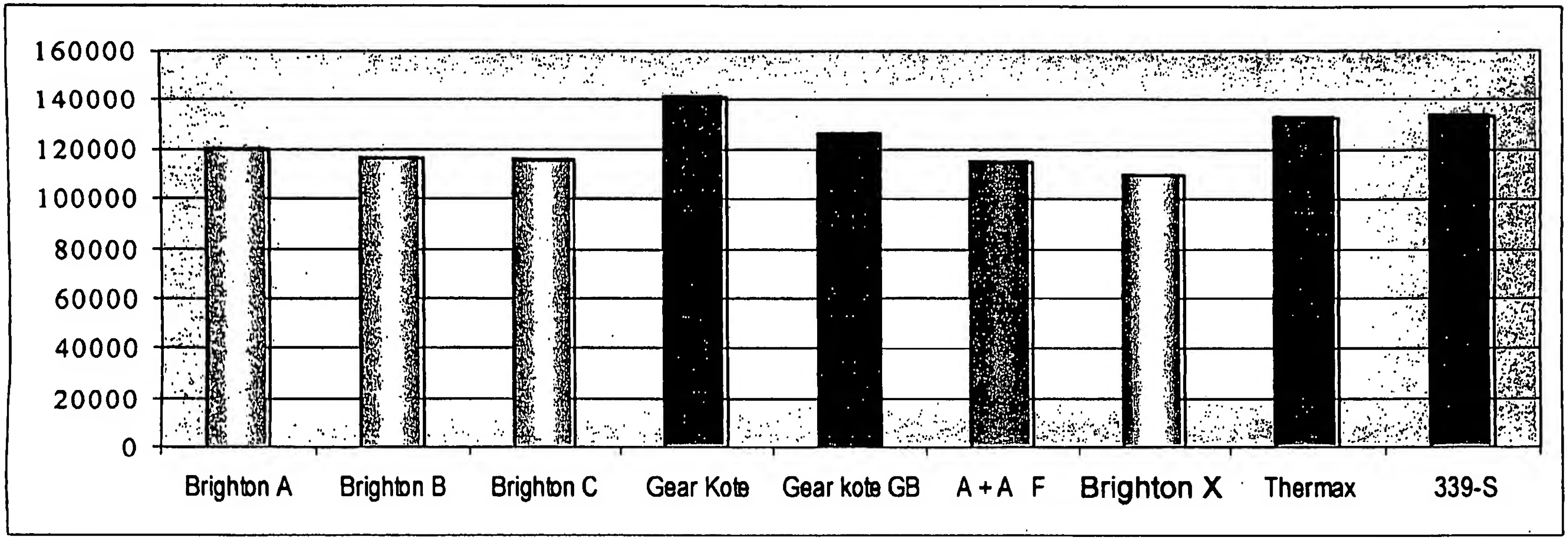
9.3 EGT Cone Surface Results

Maximum Forces during Hydraulic Expansion of the 6" Carbon Steel Pipe at Dry Friction



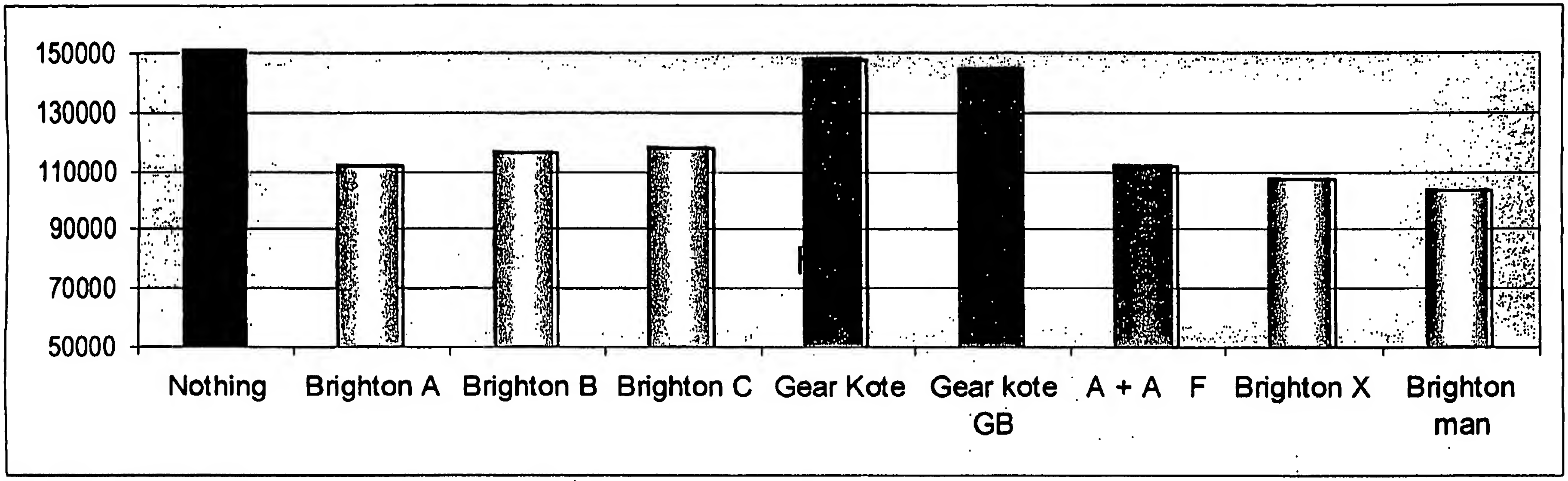
A – Honed, MEK cleaned sponge swab, Brighton coating
B - Honed, MEK cleaned sponge swab, Brighton coating
C - Honed, MEK cleaned sponge swab, Brighton coating, 1:5 dilution
Brighton man – applied manually, + Thermax – with grease
339-S Cummings grease, Brighton X – Brighton prototype, some technology uncertainty

Maximum Forces during Hydraulic Expansion of the 6 " Carbon Steel Pipe at Friction with Water



A – Honed, MEK cleaned sponge swab, Brighton coating
B - Honed, MEK cleaned sponge swab, Brighton coating
C - Honed, MEK cleaned sponge swab, Brighton coating, 1:5 dilution
Brighton man – applied manually, + Thermax – with grease
339-S Cummings grease, Brighton X – Brighton prototype, some technology uncertainty

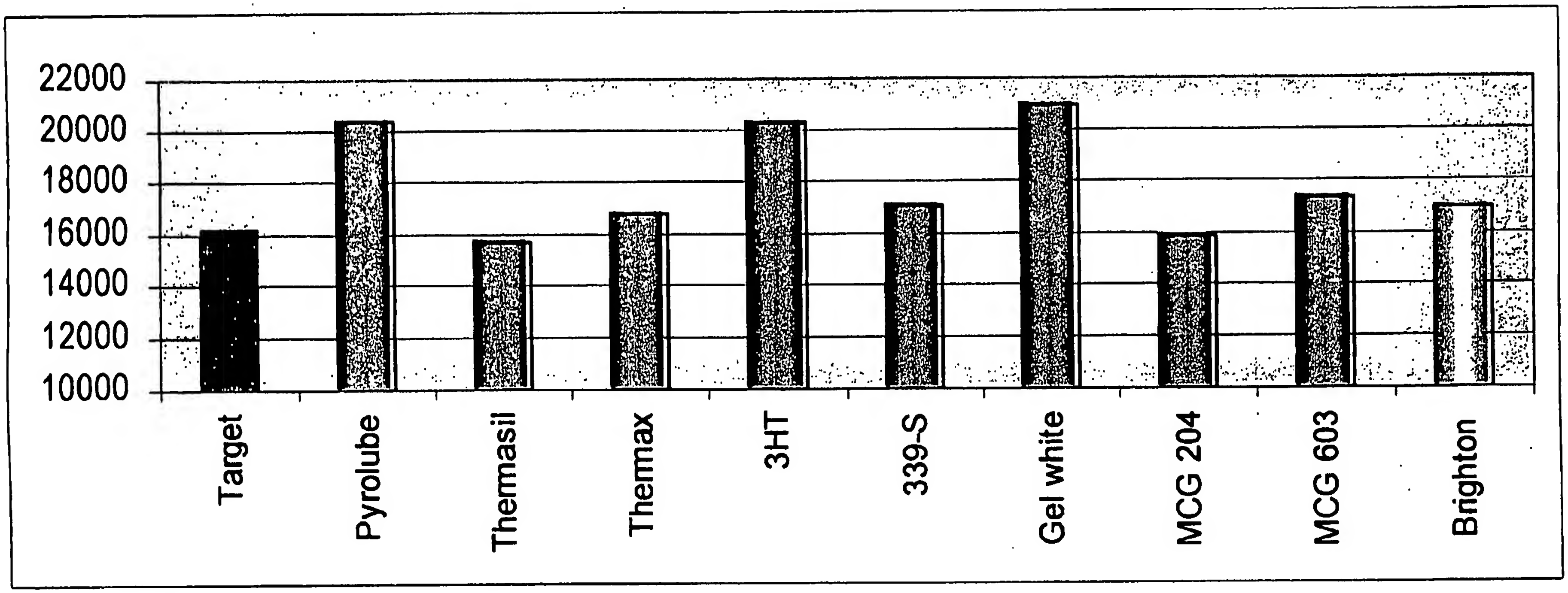
Maximum Forces during Hydraulic Expansion of the 6 " Carbon Steel Pipe at Friction with WD 40



A – Honed, MEK cleaned sponge swab, Brighton coating
B - Honed, MEK cleaned sponge swab, Brighton coating
C - Honed, MEK cleaned sponge swab, Brighton coating, 1:5 dilution
Brighton X – Brighton prototype, some technology uncertainty,
Brighton man – Brighton applied manually

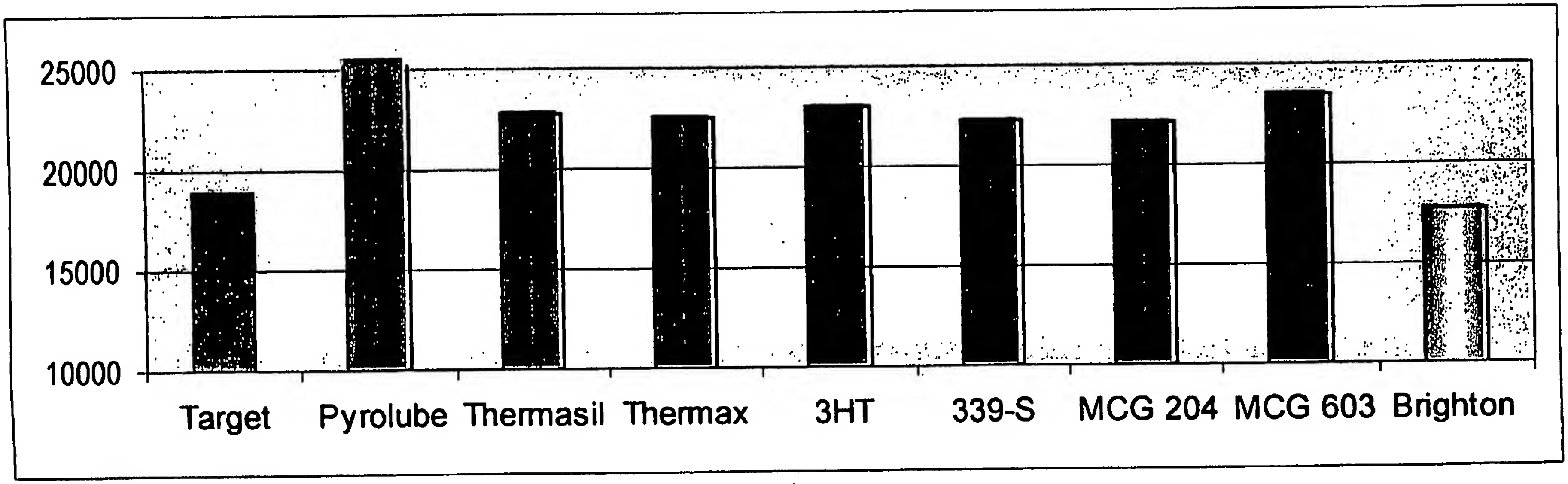
Maximum Forces during Hydraulic Expansion of the 2 "Coated Carbon Steel Pipe with Different Greases

Expansion 18 %



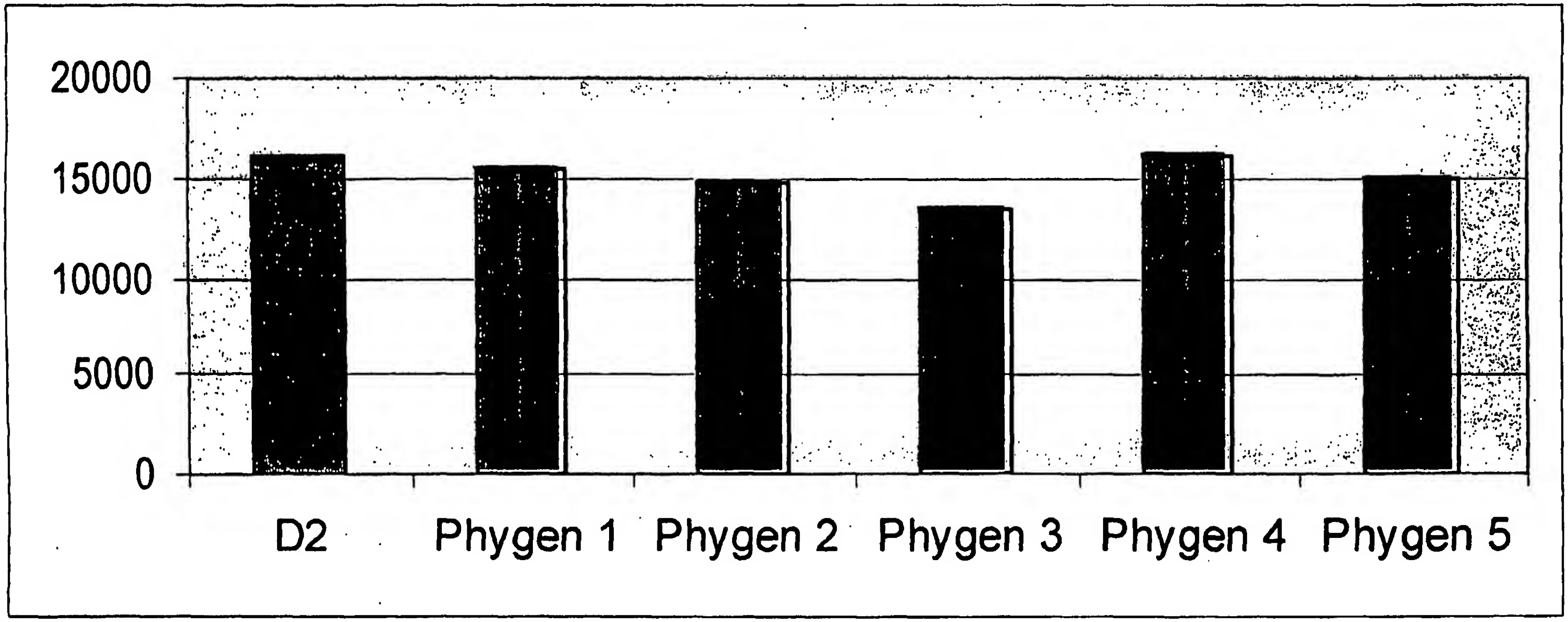
Maximum Forces during Hydraulic Expansion of the 2 " Stainless Steel Pipe with Different Greases

Expansion 18 %



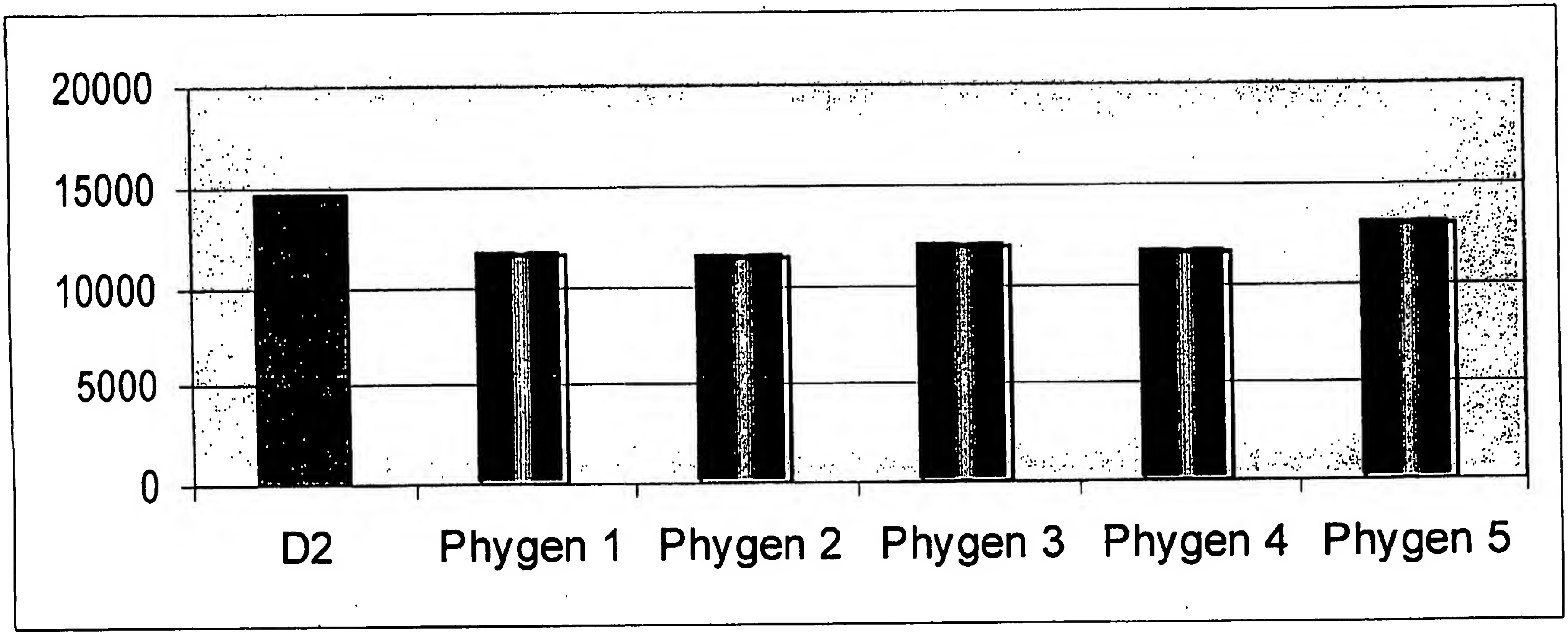
Maximum Forces during Hydraulic Expansion of the 2 "Coated Carbon Steel Pipe against Phygen Films

Expansion 18 %, pipe coated graphite-based solid lubricant



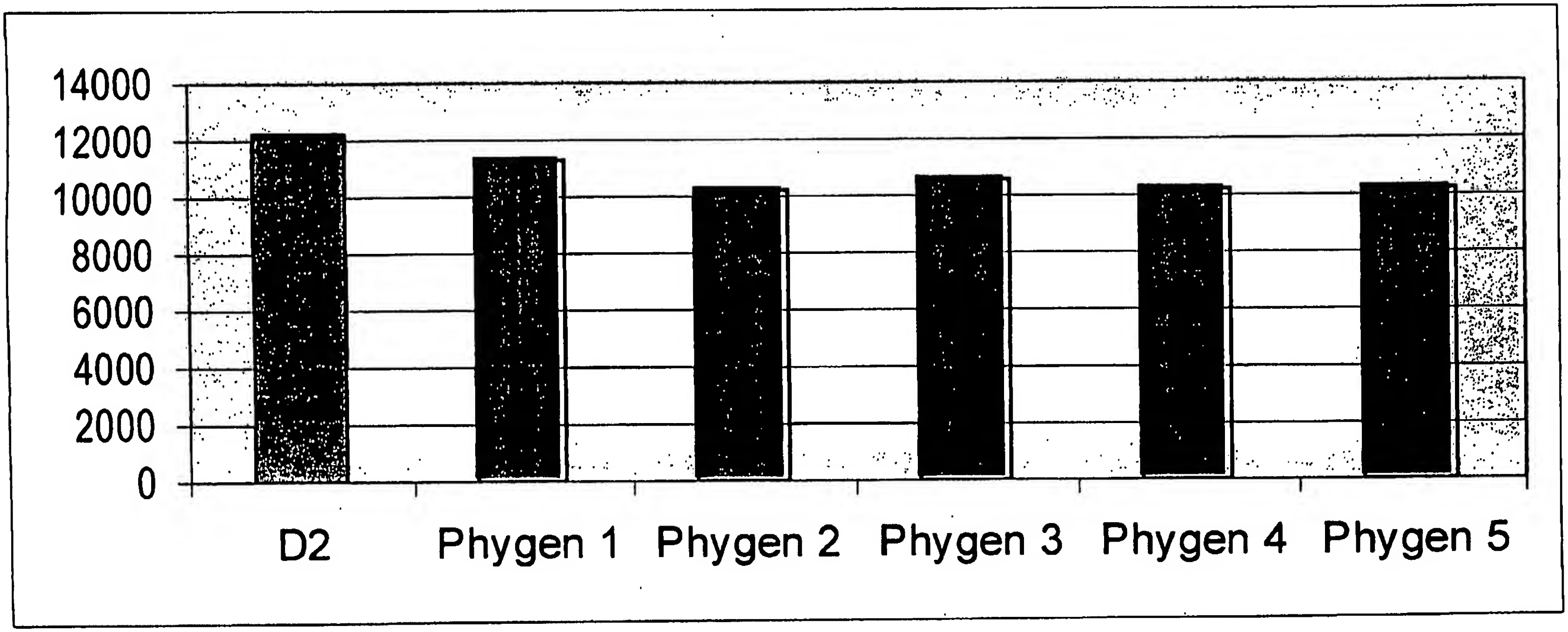
Maximum Forces during Hydraulic Expansion of the 2 "Coated 13CR Steel Pipe against Phygen Films

Expansion 11 %, pipe coated graphite-based solid lubricant



Maximum Forces during Hydraulic Expansion of the 2 "Coated 13CR Steel Pipe against Phygen Films

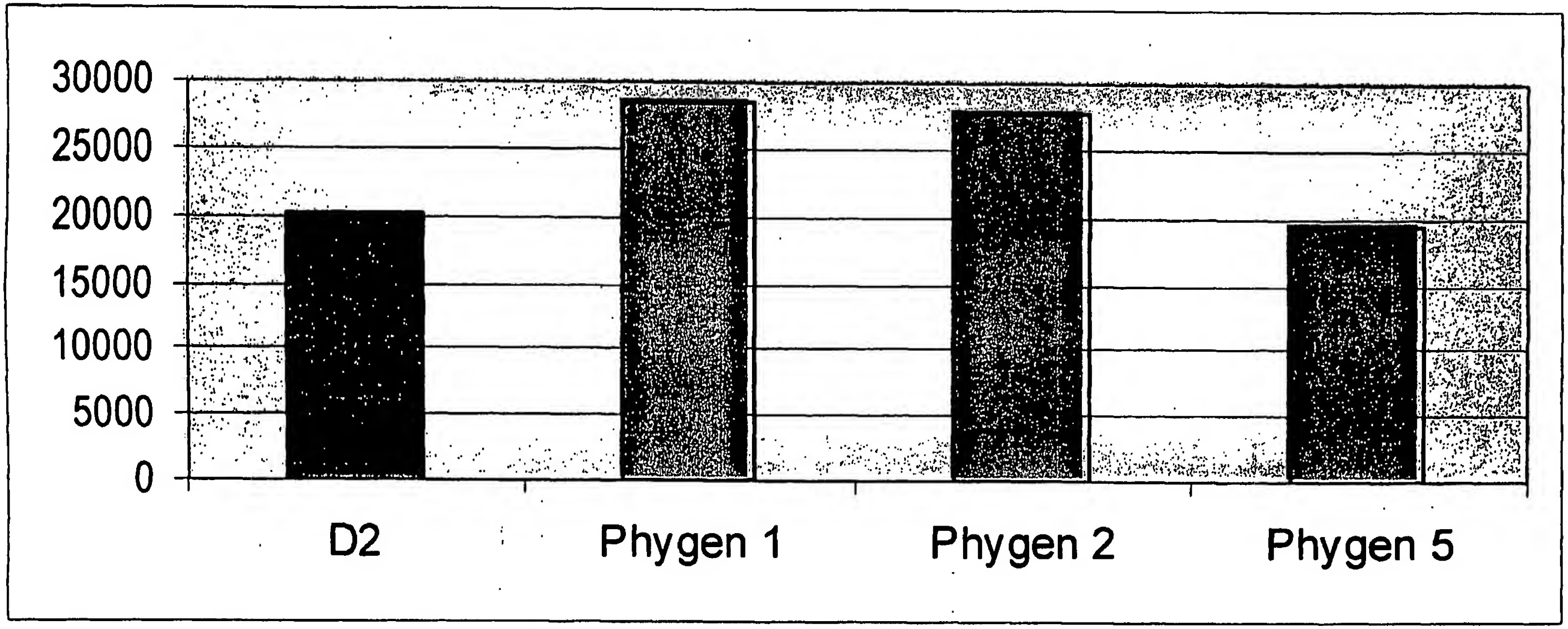
Expansion 11 %, pipe coated low friction solid lubricant



Maximum Forces during Hydraulic Expansion of the 2 "Coated Carbon Steel Pipe against Phygen Films

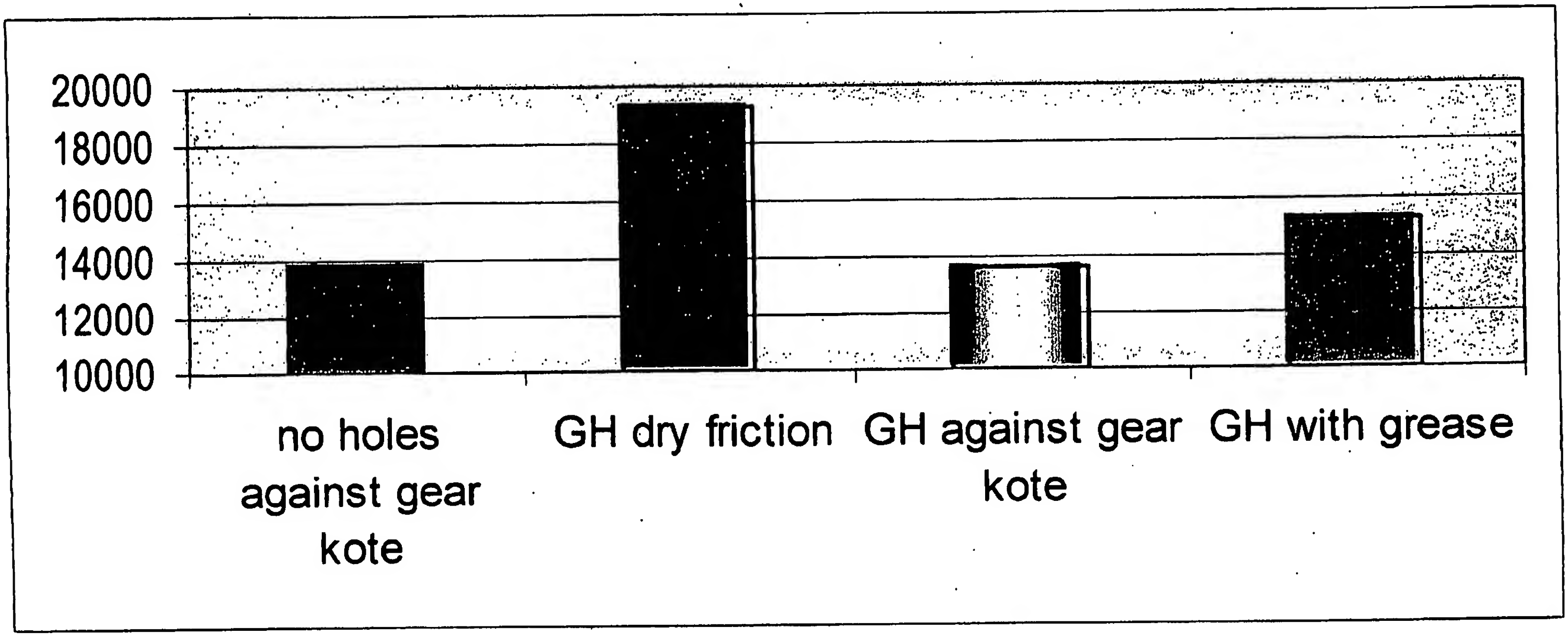
Expansion 18 %, pipe coated graphite-based solid lubricant

3HT Grease



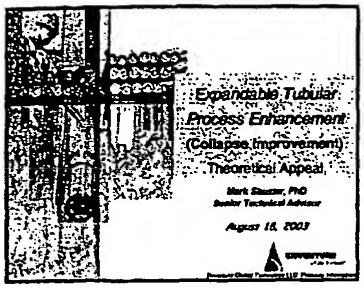
Maximum Forces during Hydraulic Expansion of the 2 "Coated Carbon Steel Pipe against Cone with transverse grooves

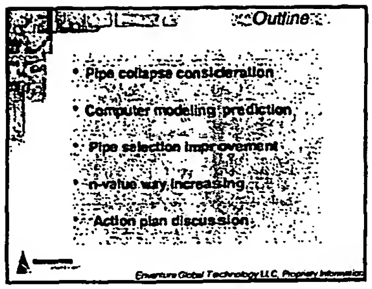
Expansion 18 %

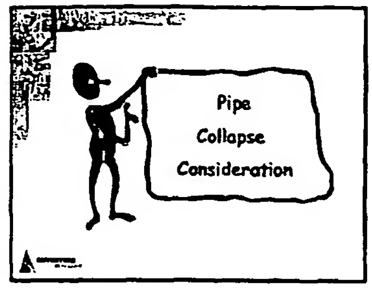


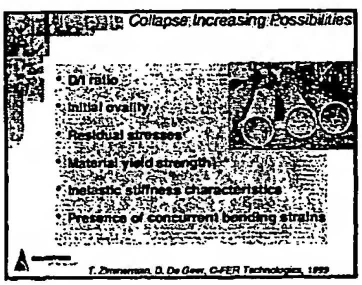
GH – Greenberg's holes (2 horizontal groves and 4 radial holes)

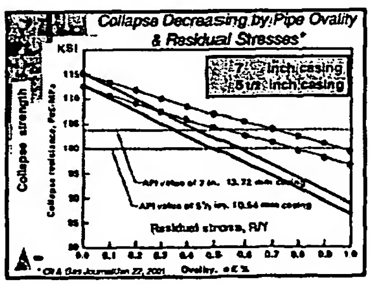
ECT-2003-27
Vmm
8-18-2003

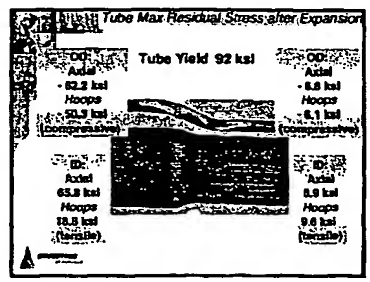


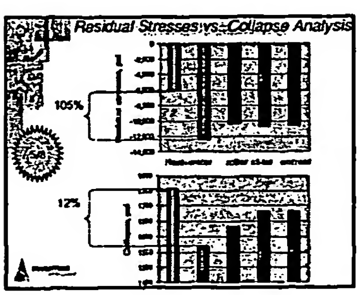


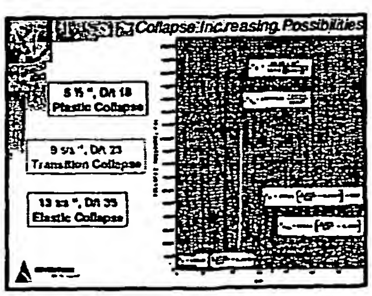


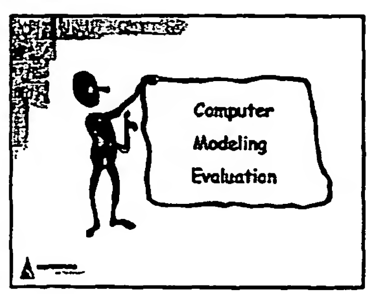


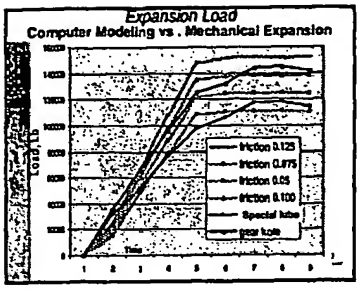


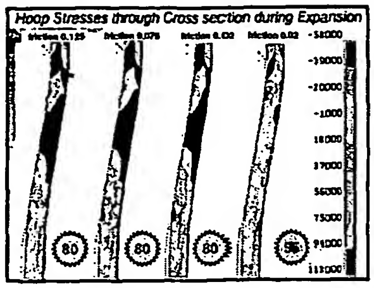


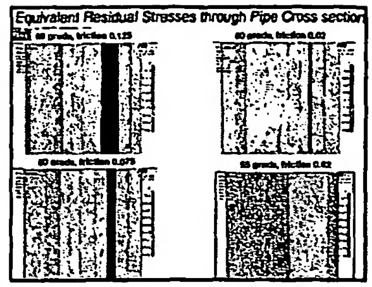


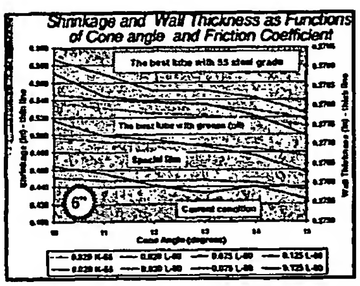


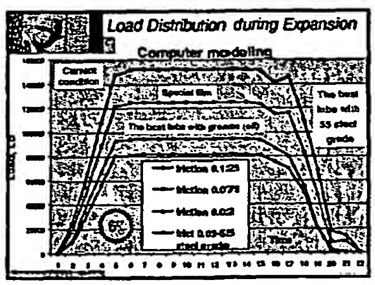


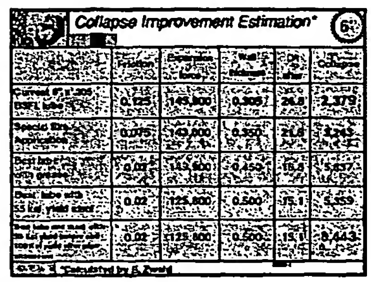


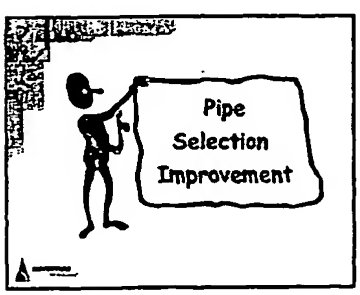


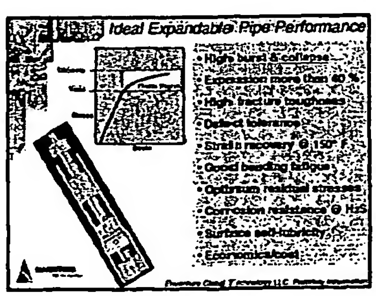


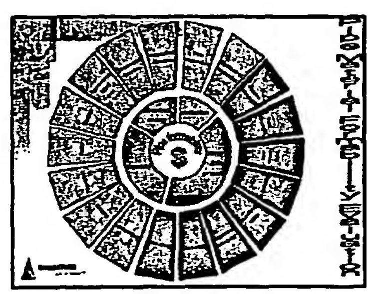












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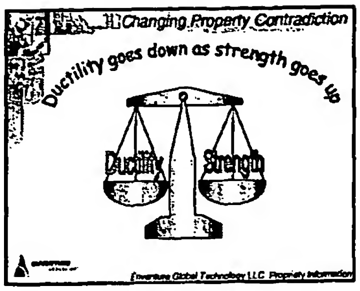

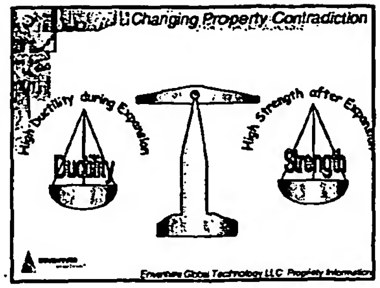

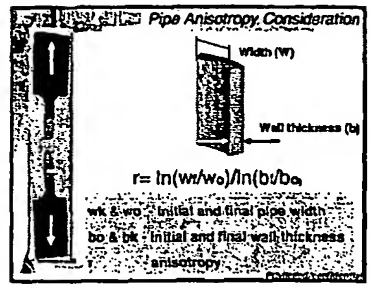

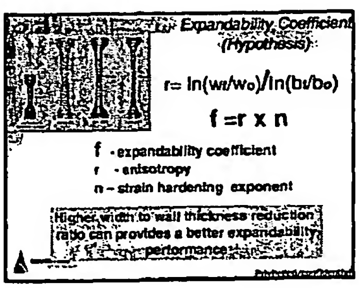

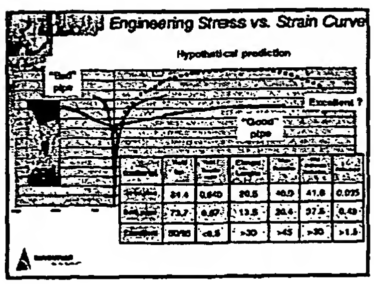

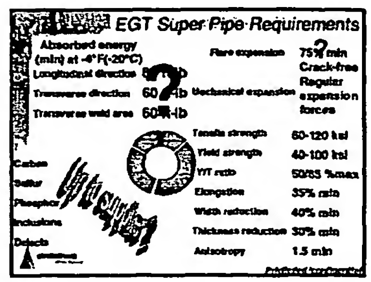

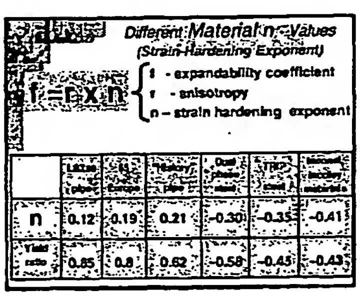

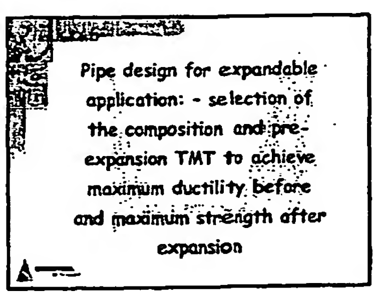

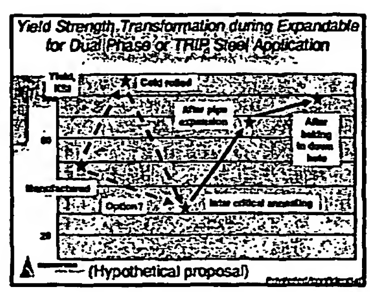

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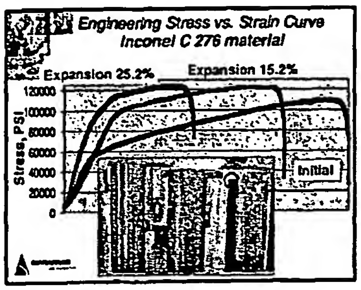
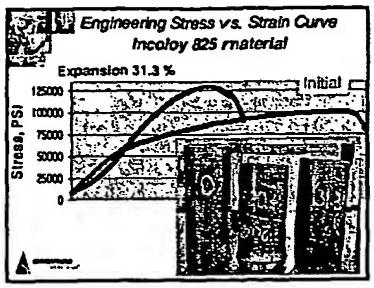
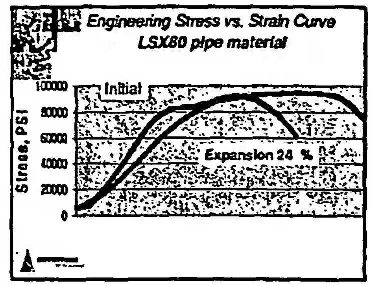
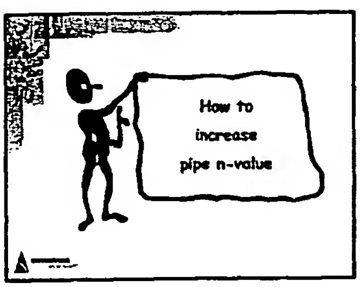
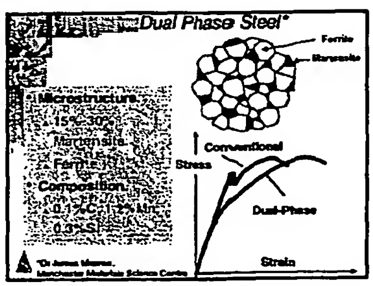
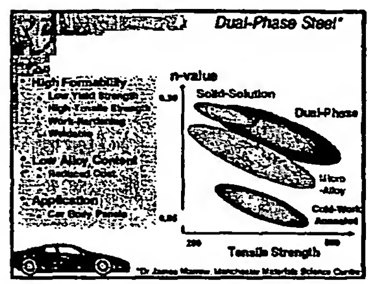

Engineering Stress vs. Strain Curve
Inconel C 276 material
Expansion 25.2%
Expansion 15.2%
Stress, PSI
120000
100000
80000
60000
40000
20000
0
Initial

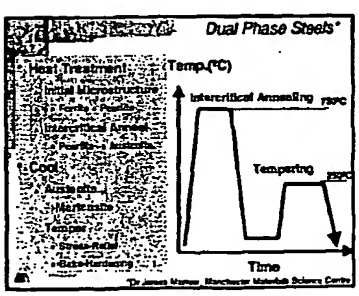

Engineering Stress vs. Strain Curve
Incoloy 825 material
Expansion 31.3 %
Initial
Stress, PSI
125000
100000
75000
50000
25000
0

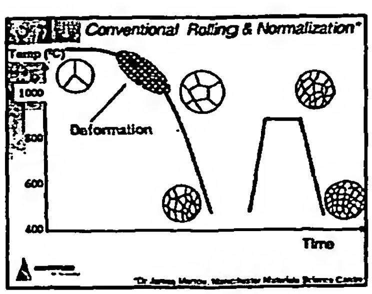

Engineering Stress vs. Strain Curve
LSX80 pipe material
Initial
Expansion 24 %
Stress, PSI
100000
80000
60000
40000
20000
0

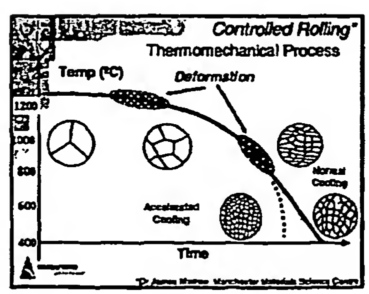

How to
increase
pipe n-value

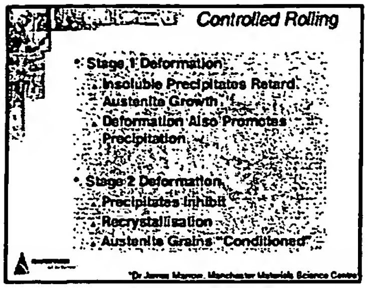

Dual Phase Steel*
Ferrite
Martensite
Microstructure
Composition
Conventional
Stress
Dual-Phase
Strain

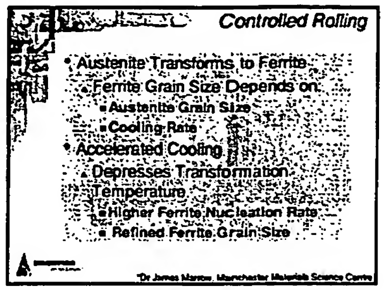

Dual-Phase Steel*
High Formability
Low Alloy Content
Application
n-value
Solid-Solution
Dual-Phase
Tensile Strength

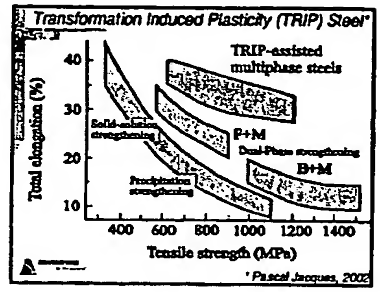

Dual Phase Steels*
Heat Treatment
Temp.(°C)
Intercritical Annealing
Tempering
Cool
Time

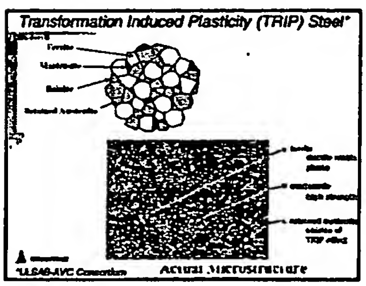

Conventional Rolling & Normalization*
Temp (°C)
1000
800
600
400
Deformation
Time

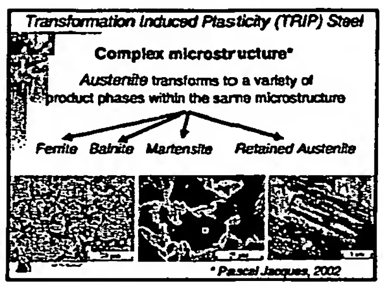

Controlled Rolling*
Thermomechanical Process
Temp (°C)
Deformation
Normal Cooling
Accelerated Cooling
Time

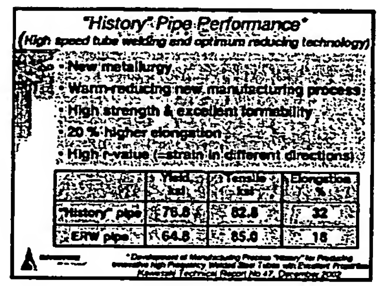




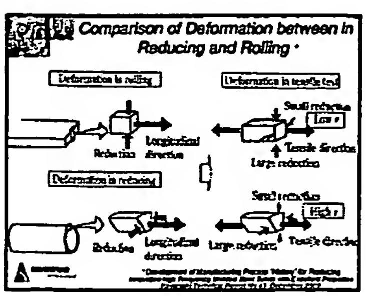


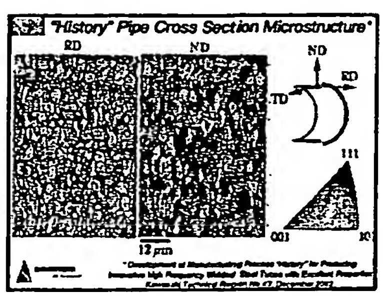


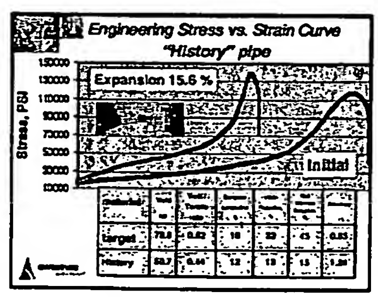




	Yield ksi	Tensile ksi	Elongation %
"History" pipe	76.8	82.8	32
ERW pipe	64.8	85.0	16







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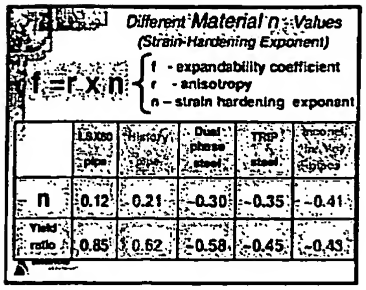

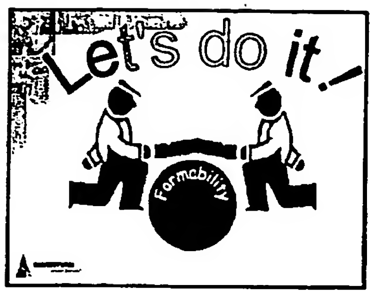

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EGT-2003-28
vmw
8/29/2003

Expandable Tubular Projects

Review and Technical Discussion

By: Matt Shade and Grigoriy Grinberg

Date: 8/27/03

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Agenda

- ➢ **Overview of Projects**
  - ⇨ **Low Friction Tool for Expandable Tubular**
  - ⇨ **Changeable Diameter Tool for Expandable Tubular**

- ➢ **Technical Discussion**
  - ⇨ **Low Friction Tool for Expandable Tubular**
    - •**High Efficiency Lubrication System**
    - •**Cone Design Test Results**
    - •**Lubricant Analysis and Results**
    - •**Hydro-Electric Concept Feasibility**
  - ⇨ **Changeable Diameter Tool for Expandable Tubular**
    - •**High Efficiency Lubrication System**
    - •**Actuator Control Signals**
    - •**Hydroforming or Hydro-Electric Impulse to Create Bell Section or Launcher**

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Overview of Projects

- ➢ **Low Friction Tool for Expandable Tubular**
  - •Conceptualization - Phase 1
  - •Concept Selection - Phase 2
  - •Tool Design - Phase 3
- ➢ **Changeable Diameter Tool for Expandable Tubular**
  - •Feasibility Study
  - •Preliminary Concepts

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Low Friction Tool for Expandable Tubular

➢Conceptualization - Phase 1

The objective of this phase was to generate low friction tool concepts and recommend potential tool materials, coatings, and lubricants.

Results

Conceptual Designs

High Efficiency Lubrication System with "Mud" as a Lubricant
High Efficiency Lubrication System with Commercial Lubricant
High Pressure Assisted Lubrication System with "Mud" as a Lubricant
High Pressure Assisted Lubrication System with Commercial Lubricant
Hydro-Electric Assisted Lubrication System
Magneto-Dynamic Assisted Lubrication System

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Low Friction Tool for Expandable Tubular

Results (Continued)

Conceptual Design Features

High Efficiency Lubrication System

Polygon Pyramid Cone Surface with Lubrication Channels

High Performance Tool Material

Low Friction PVD or CVD Coating

Lubricant with Extreme Pressure Properties

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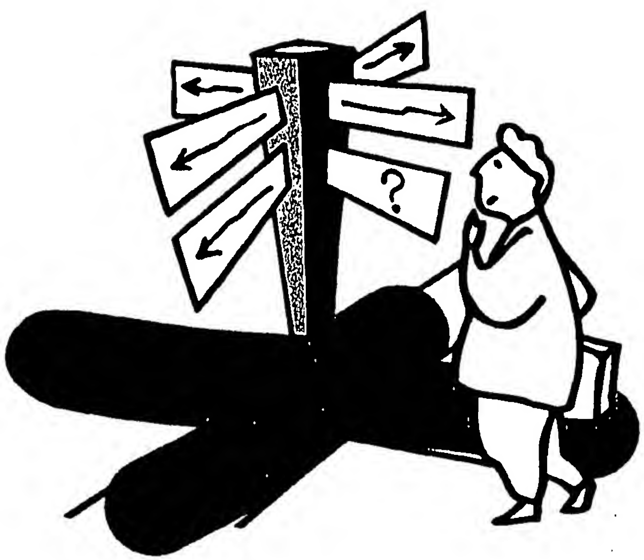
Low Friction Tool for Expandable Tubular

Results (Continued)

Conceptualization Paths

Short Term - High Efficiency Lubrication System

Long Term - High Pressure Assisted Lubrication System (Multiplicator, Hydro-Electric)



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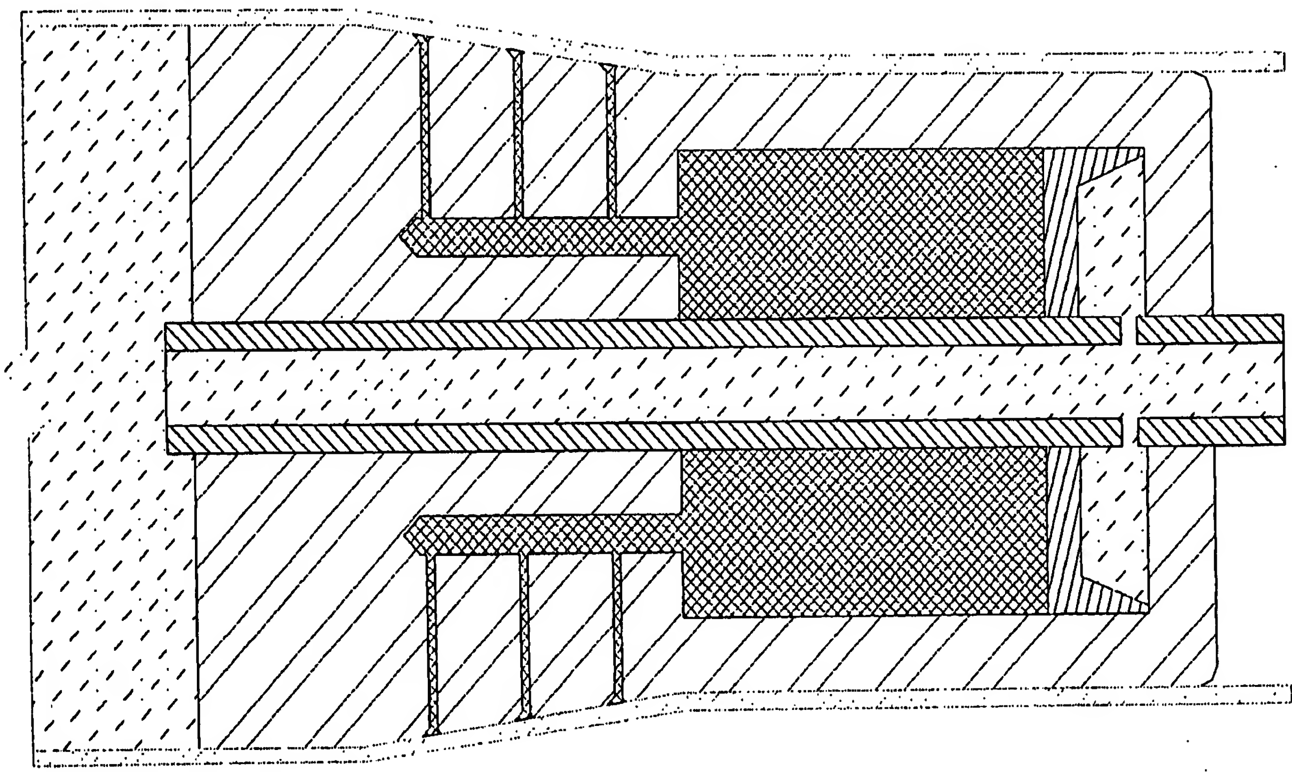
Low Friction Tool for Expandable Tubular

- **Conceptualization Paths**

Short Term - High Efficiency Lubrication System using System Pressure



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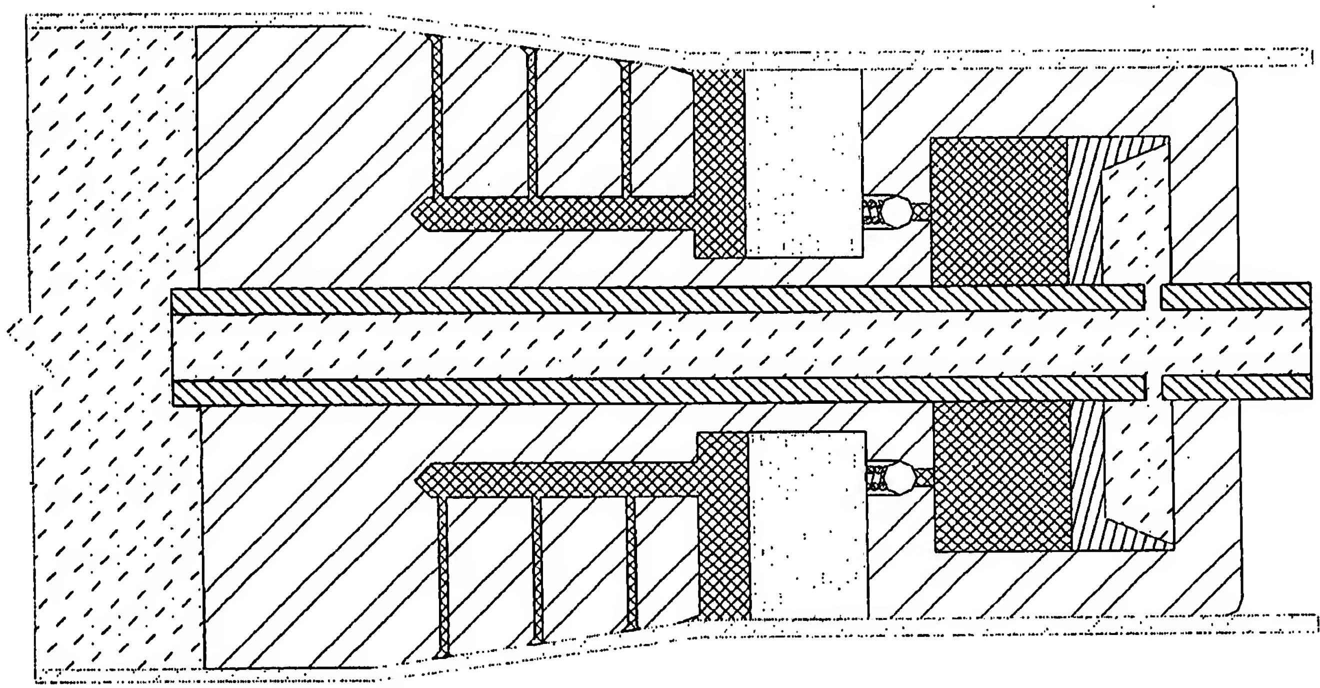
Low Friction Tool for Expandable Tubular

- **Conceptualization Paths**

  Long Term, - High Pressure Assisted Lubrication System



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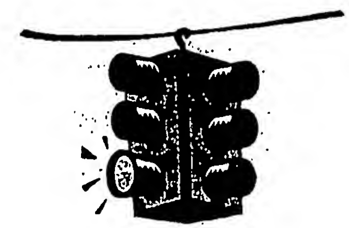
Low Friction Tool for Expandable Tubular



➢**Conceptualization - Phase 1**

STATUS: Completed 5/9/2003

Six low friction tool concepts generated, two paths identified for final tool design.

Testing required to determine optimum concept design features.

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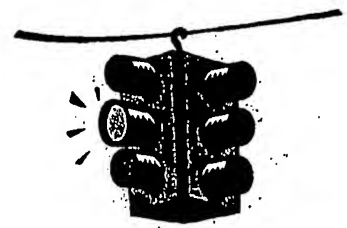
Low Friction Tool for Expandable Tubular

➢Concept Selection - Phase 2

The objective of this phase was to select the a concept and the optimum design features for the tool design phase.

STATUS: **Testing in Progress**



Testing and Evaluation Areas

Cone Surfaces
Lubricants/Coatings
Tool Materials

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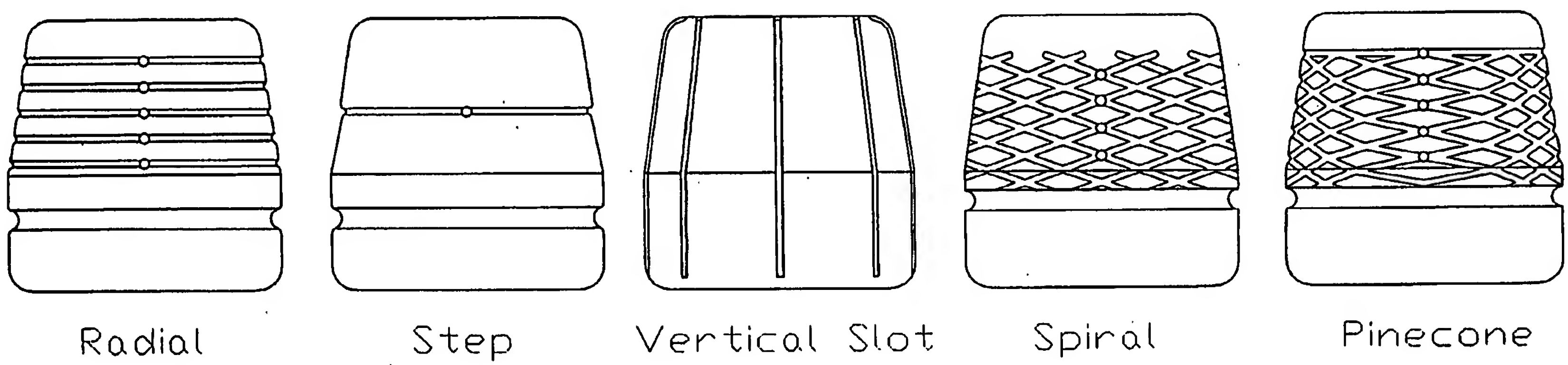
Low Friction Tool for Expandable Tubular

Cone Surface Testing



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Low Friction Tool for Expandable Tubular

Lubricants/Coatings

Enventure lubricant and coating testing program in progress.

Tool Materials

Enventure tool material testing program in progress.

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Low Friction Tool for Expandable Tubular

➢Tool Design - Phase 3

The objective of this phase was to complete the tool design for a specific diameter experimental tool.

STATUS: **Ready to Start**

Will finalize schedule, tool material, lubricant, and identify resources for final design this week.

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Overview of Projects

- ➢ **Changeable Diameter Tool for Expandable Tubular**
    - **Feasibility Study**
    - **Preliminary Concepts**

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Changeable Diameter Expandable Tubular Tool

➢Feasibility Study- Phase 1

The objective of this phase was to determine feasibility of a changeable diameter expandable tubular tool and generate preliminary concepts if feasible.

1. **Select Process for Expansion**
2. **Identify Key Requirements to Justify Feasibility**
3. **Determine Feasibility**

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Changeable Diameter Tool for Expandable Tubular

1. Expandable Tubular Process Selection

Industry Processes and Intellectual Property Review

- ⇒Rotary Process
- ⇒Self Anchoring Process
- ⇒Bottom-up Process

Enventure Expandable Tubular Process, Bottom-up Tool Using Hydraulic Pressure Feasible for Changeable Diameter Tool.

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Changeable Diameter Tool for Expandable Tubular

2. Key Requirements to Justify Feasibility

Tool Design - Cone
Method to Seal Tool During Expansion
Simple Engagement Device

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Changeable Diameter Tool for Expandable Tubular

Tool Design - Cone

Configurations
- ⇒Wedges
- ⇒Segments
- ⇒Spiral

A Changeable Diameter Cone Is Feasible, Independent Segments Most Functional Design for this Application.

Method to Seal Tool During Expansion

Sealing Methods
- ⇒Two Stage
- ⇒One Stage

Device for Sealing a Bottom-up Changeable Diameter Tool Is Feasible.

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Changeable Diameter Tool for Expandable Tubular

Simple Engagement Device

Design and Actuation

A Simple Engagement Device Is Feasible, A Mechanical Device Driven by Input Pressure Is The potential Solution.

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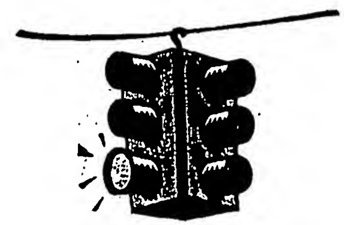
Changeable Diameter Tool for Expandable Tubular

- **Feasibility Study - Phase 1**



STATUS: Completed 8/11/2003

Changeable Diameter Tool Is Feasible!

Feasibility was justified based on an engineering review, industry review and intellectual property review.

The feasibility study generated two preliminary conceptualization paths.

Changeable Diameter Tool for Expandable Tubular

➢Preliminary Concepts

Short Term: Two-Stage Tool Concept
Long Term: Single-Stage Tool Concepts

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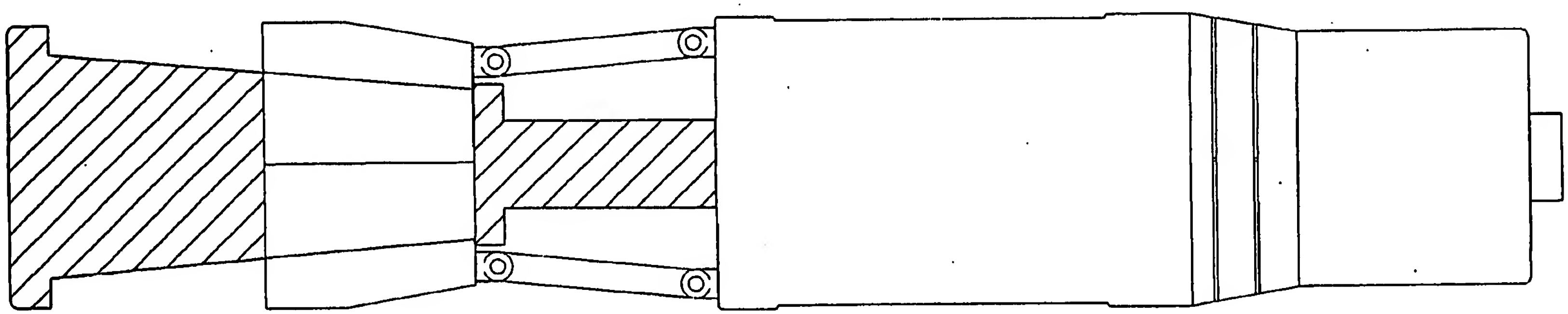
Changeable Diameter Tool for Expandable Tubular

- **Short Term**: Two-Stage Tool Concept



- Bottom-Up Design
- Increased Expansion Ratio
- Ease of Implementation
- Minimized Risk of Sticking

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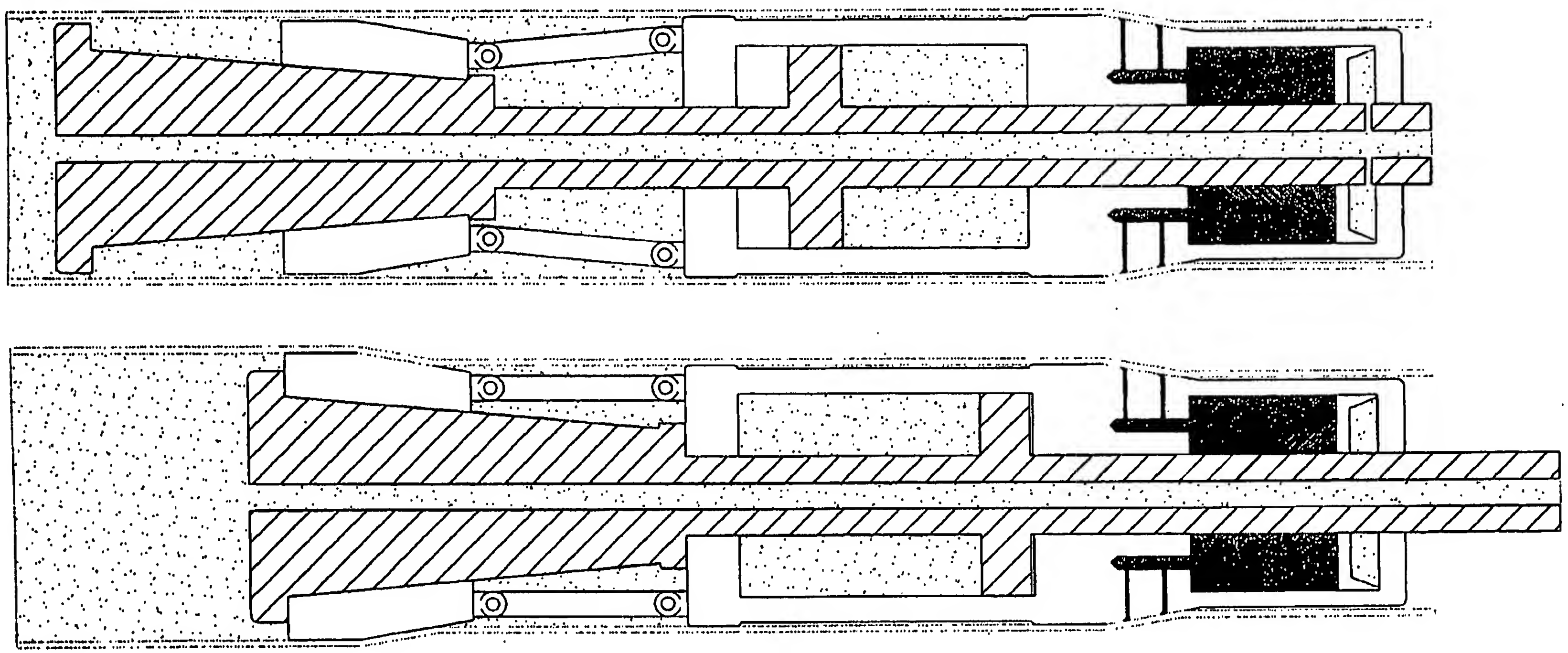
Changeable Diameter Tool for Expandable Tubular

- **Short Term**: Two-Stage Tool Concept



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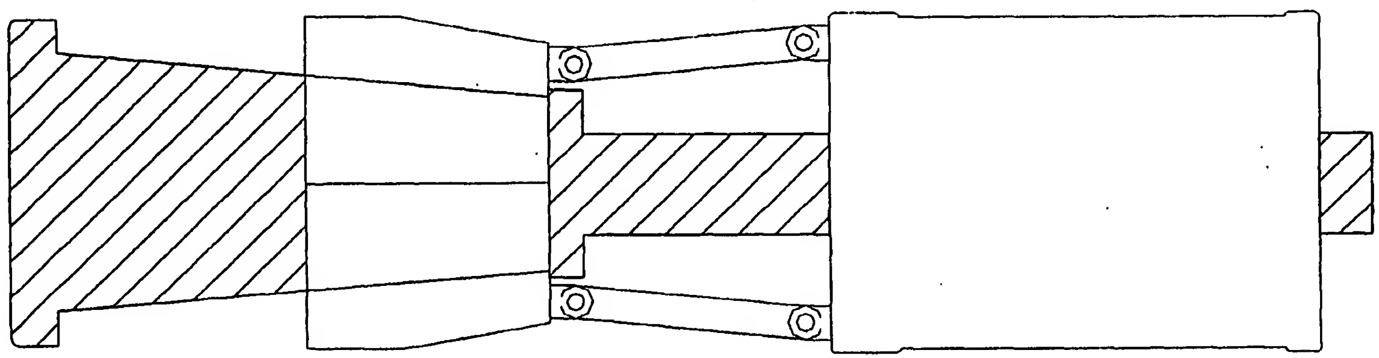
Changeable Diameter Tool for Expandable Tubular

- **Long Term**: Single-Stage Tool Concept (1)



- Bottom-Up Design
- No Launcher
- Minimized Risk of Sticking

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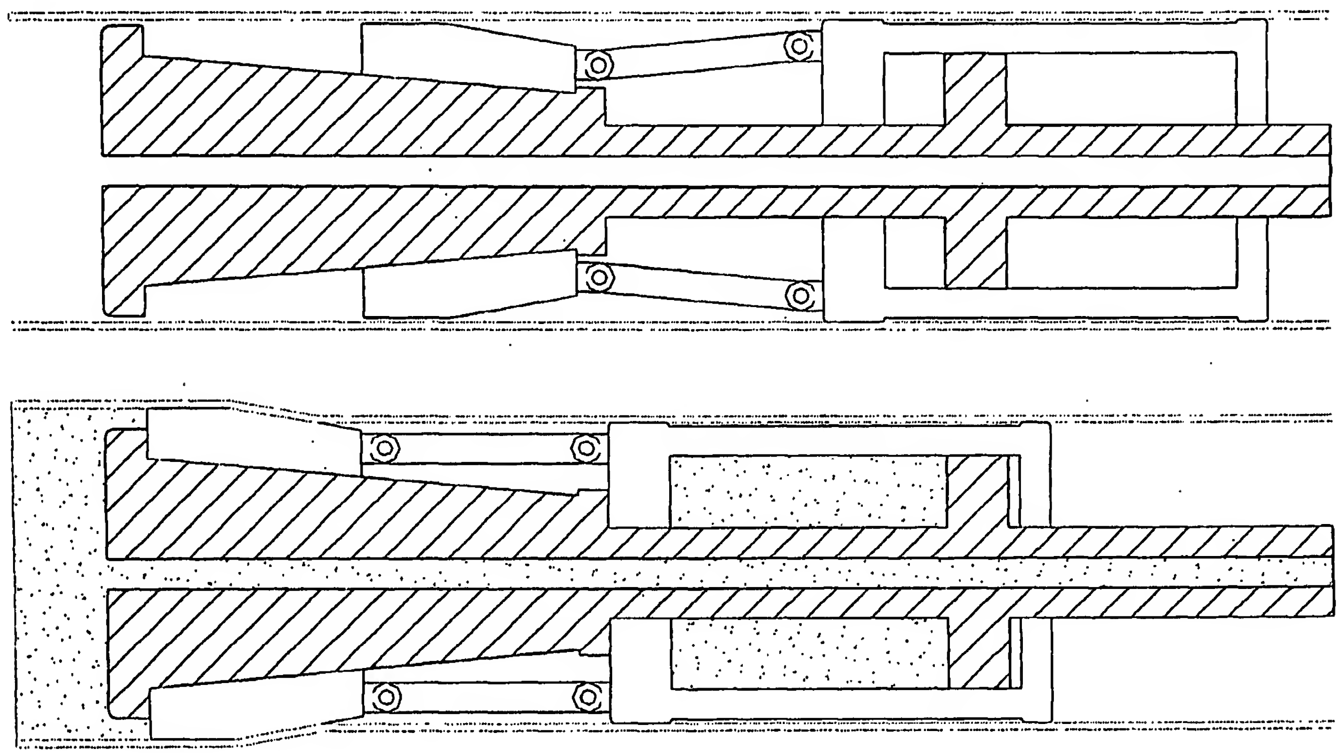
Changeable Diameter Tool for Expandable Tubular

- **<u>Long Term</u>:** Single-Stage Tool Concept (1)



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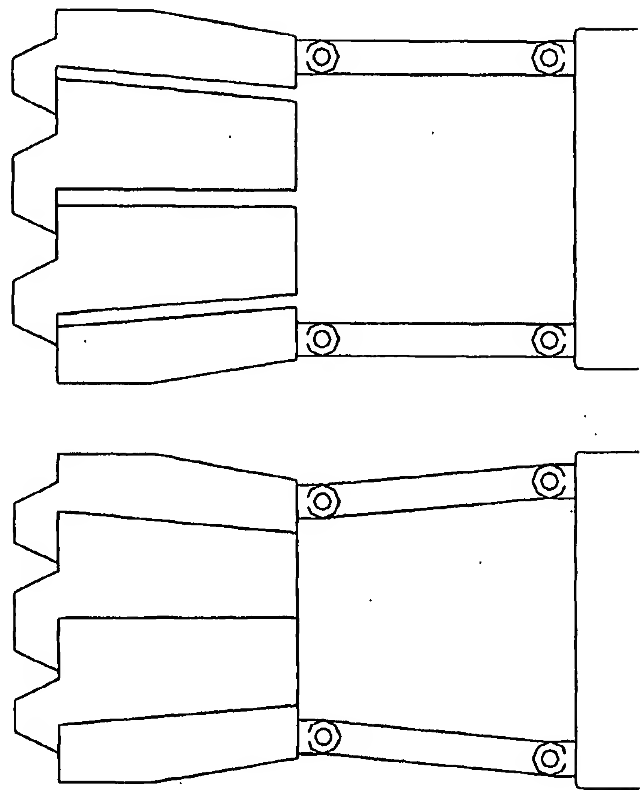
Changeable Diameter Tool for Expandable Tubular

- **Long Term**: Single-Stage Tool Expanding Cone Concept (1)



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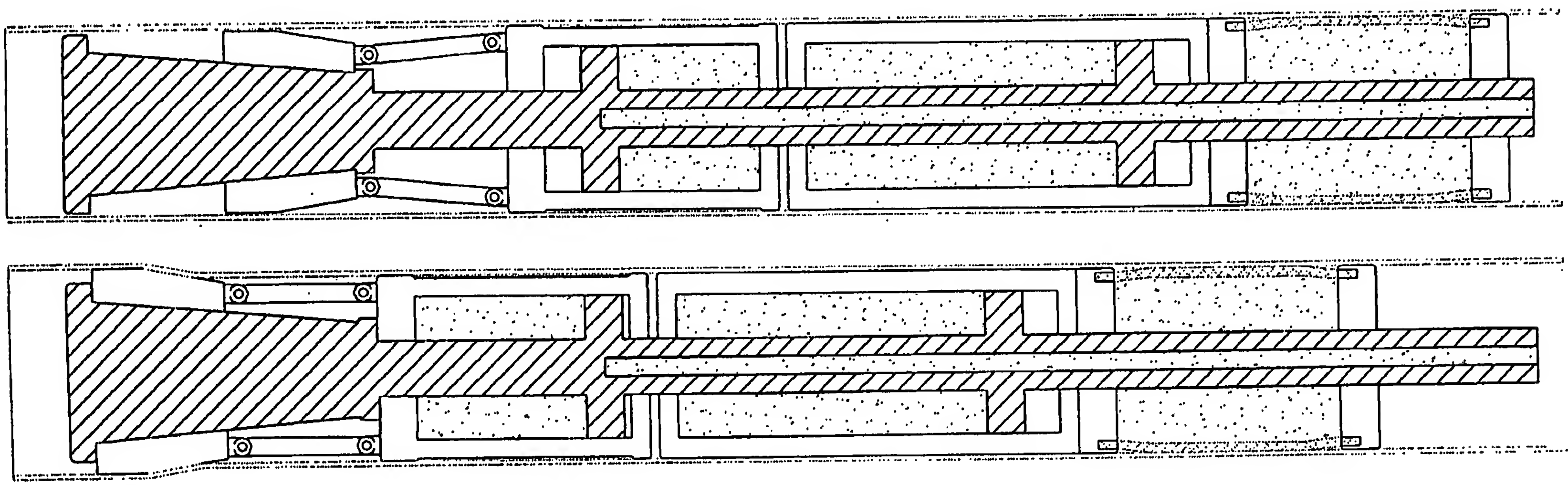
Changeable Diameter Tool for Expandable Tubular

- **Long Term**: Single-Stage Tool Concept (2)



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Technical Discussion

⇨ Low Friction Tool for Expandable Tubular
- High Efficiency Lubrication System
- Cone Design Test Results
- Lubricant Analysis and Results
- Hydro-Electric Concept Feasibility

⇨ Changeable Diameter Tool for Expandable Tubular
- High Efficiency Lubrication System
- Actuator Control Signals

Technical Discussion

⇨ Low Friction Tool for Expandable Tubular

- High Efficiency Lubrication System
- Cone Design Test Results
- Lubricant Analysis and Results
- Hydro-Electric Concept Feasibility

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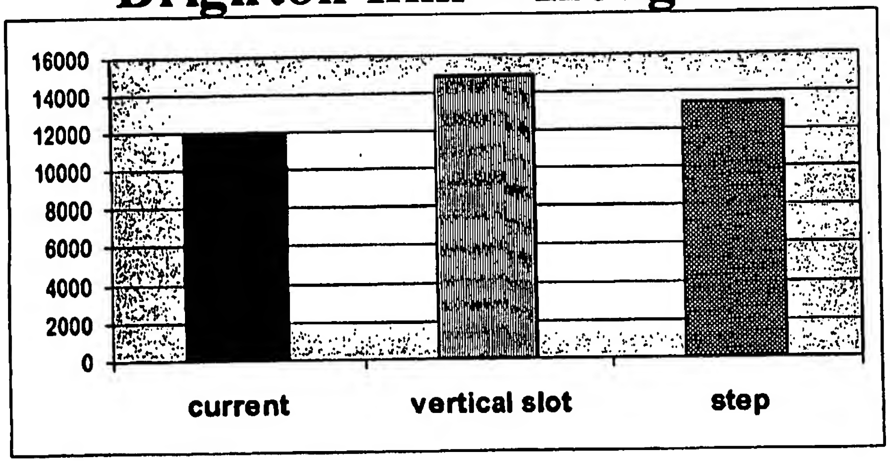
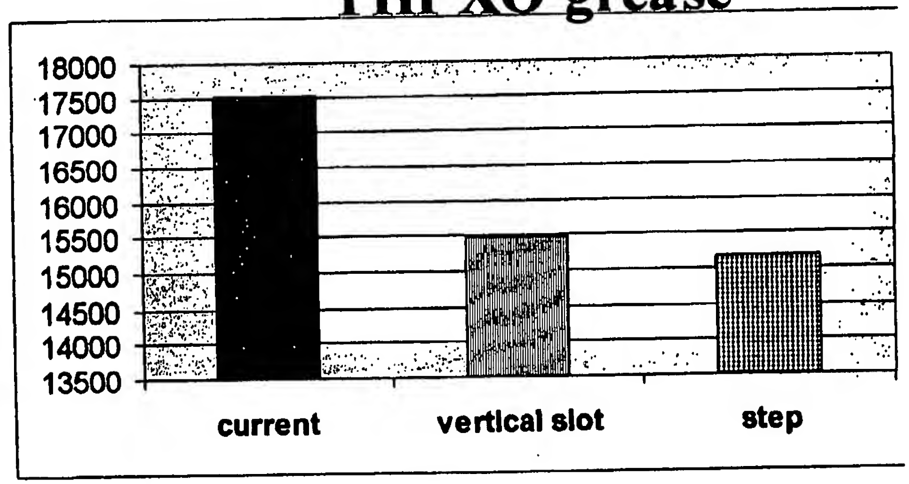
Maximum Forces during Mechanical Expansion of the 1 5/8 " Carbon Steel Pipe with Different Lubricants and Cone Shapes

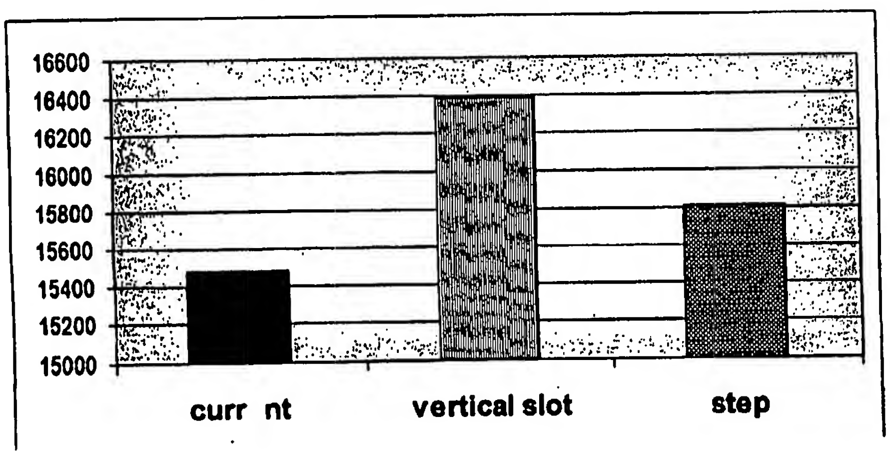
Brighton film + Houghton oil



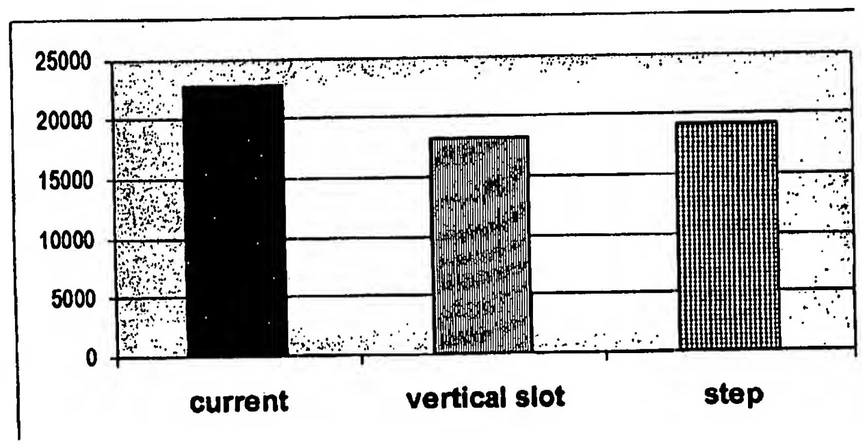
THI XO grease



Oleon oil

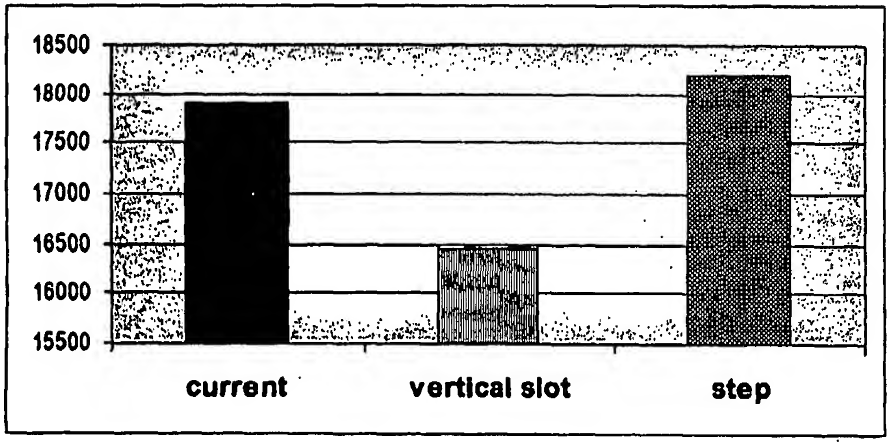


Thermax grease

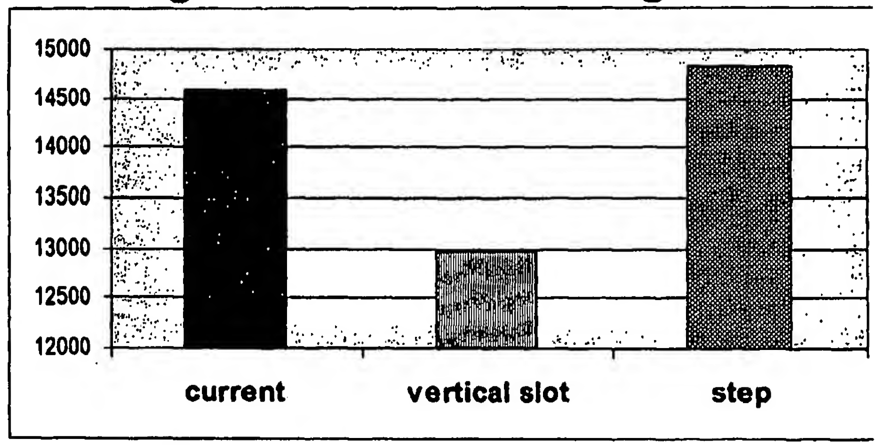


Maximum Forces during Mechanical Expansion of the 1 5/8 " Carbon Steel Pipe with Different Lubricants and Cone Shapes

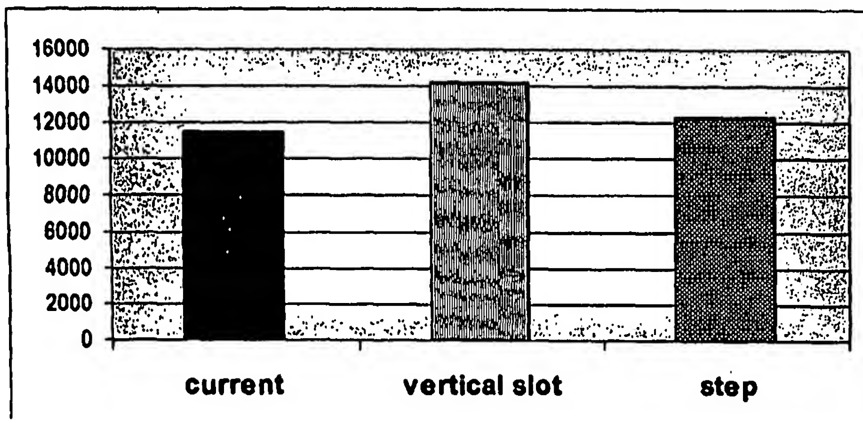
Gear Kote coating



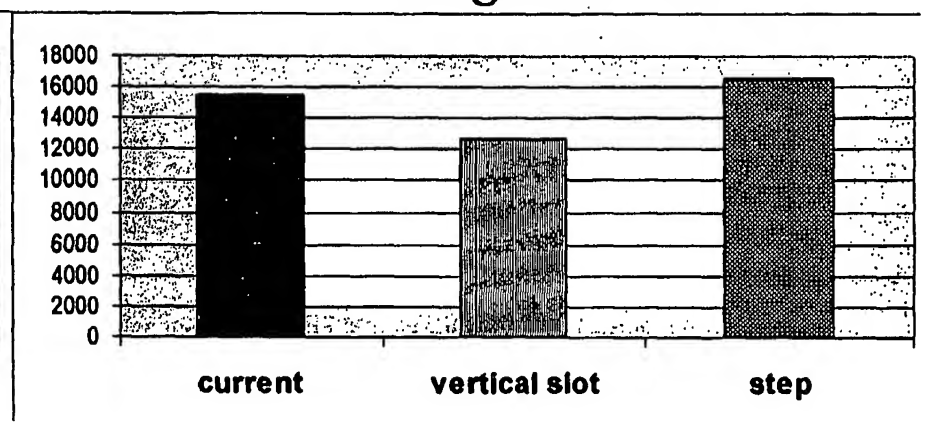
Brighton film + THI XO grease



Brighton film + Oleon oil

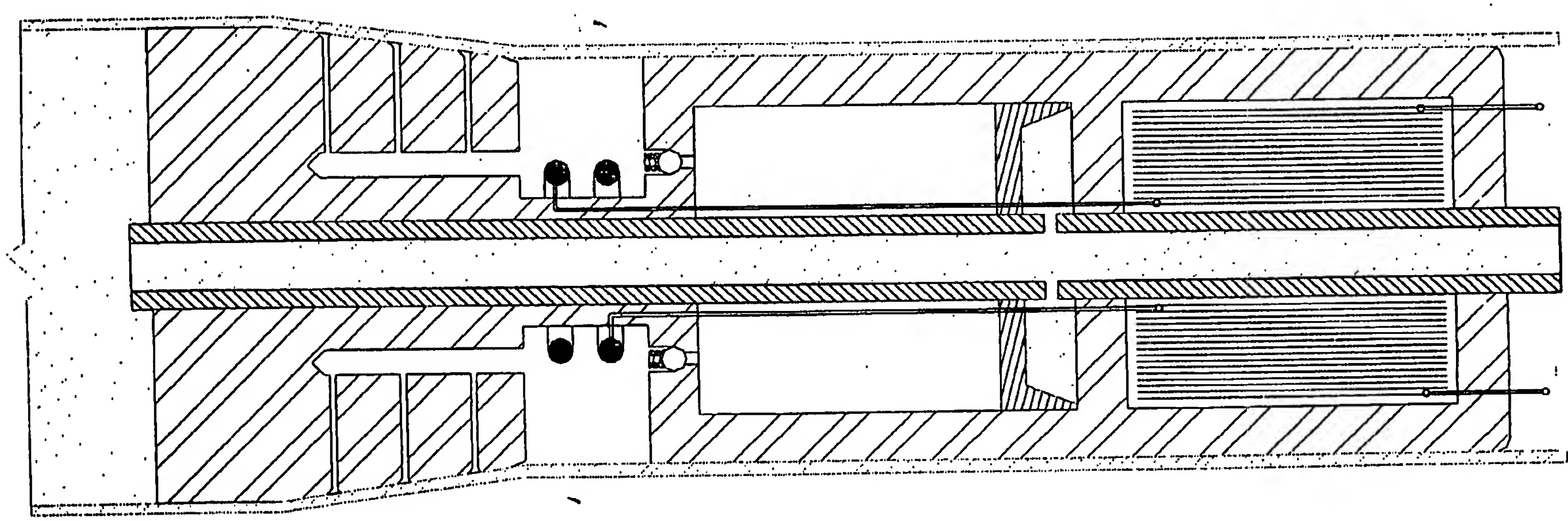


Brighton film



Technical Discussion

➢ **Hydro-Electric Concept Feasibility**
- **Feasibility Report**
- **Next Steps**



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Technical Discussion

⇨Changeable Diameter Tool for Expandable Tubular

- High Efficiency Lubrication System
- Actuator Control Signals
- Hydroforming or Hydro-Electric Impulse to Create Bell Section or Launcher

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Project Title:

Feasibility of Hydro-Electric Lubrication System
In Expandable Tubular

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1.0 Project Summary

1.1 Abstract

A Hydro-Electric assisted lubricant injection system is a viable alternative to, and may have advantages over, both the multiplicator (high-pressure lubricator) concept as well as the unassisted lubrication concept. The Hydro-Electric approach works by triggering a high-pressure gaseous expansion within an enclosed volume of lubricant by means of an electric discharge. The expansion should create a pressure in the area of 15ksi, allowing more lubricant to flow between the tool and the tubular and thereby reducing the friction. Potentially this could reduce the working pressure behind the cone. Certain considerations, described herein, need to be taken into account in developing this design concept.

2.0 Project Description

2.1 Concept Design Description

The Hydro-Electric assist concept relies on a bank of capacitors that are located directly above main portion of the tool and circumscribe the "mud" delivery tube. Low impedance coaxial cables should be used to provide power to the capacitors. Alternatively, the tubular may be used as a ground plate along with a second wire. This configuration, however, could have unacceptably high impedance that should be rigorously investigated. The actual discharge occurs between two electrodes in a volume of lubricant that acts as a dielectric. It is important, therefore, to carefully choose both the electric and thermodynamic properties of the lubricant, in addition to its coefficient of friction. When the dielectric between the electrodes breaks down, a high temperature arc is created which vaporizes some of the dielectric. Due to the incompressibility of fluids, the vaporization creates a pulse of pressure, which complements the existing fluid pressure.

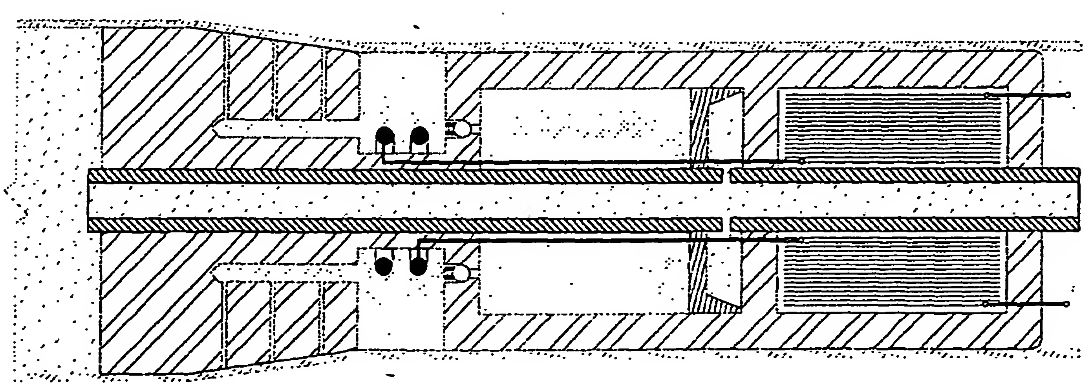

Figure 1. Expandable Tubular Tool with Hydro-Electric Assisted Lubrication System

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3.0 Hydro-Electric Principles and Equations

3.1 Thermodynamic Properties

Because of the non-ideal nature of the vaporized dielectric medium, the Van der Waals equation (Eq. 1) was manipulated to express pressure as a function of the ratio of dielectric medium density, average molar mass, and the dielectric's boiling point (Eq. 2). Since the volume of the discharge chamber is not well defined, these constraints have to be used. Because addition of the heat of vaporization does not change the temperature, it is assumed in Equation 2 that the vaporization takes place at about the boiling point of the dielectric. However, increases beyond this temperature should have no negative effect on vaporization. Furthermore, there is no direct mathematic relationship between the discharge energy and the pressure created by the vaporization. Molar mass of the dielectric will need to be calculated experimentally or mathematically if all the components of the dielectric medium are known. The constants 'a' and 'b' are experimentally determined. However, these quantities may be available in engineering tables based on the choice of lubricant.

$$\left[P + a\left(\frac{n}{V}\right)^2\right](V - nb) = nRT \qquad \text{Eq. (1)}$$

Whereas:

P – Pressure [psi]
T – Temperature [K]
R – 1.206 [L-psi/K-mol]
b – Experimental Constant Relating to Molecular Volume
V – Volume of Vaporized Lubricant
n – Moles of Lubricant [mols]
a – Experimental Proportionality Constant

$$P = \frac{RT_b}{(\frac{M}{\rho}) - b} - a\left(\frac{\rho}{M}\right)^2 \qquad \text{Eq. (2)}$$

Whereas:

P – Pressure [psi]
M – Av. Lubricant Molar Mass
R – 1.206 [L-psi/K-mol]
b – Experimental Constant Relating to Molecular Volume
T_b – Lubricant's Boiling Point [°K]
ρ – Lubricant Density
a – Experimental Proportionality Constant

The effective discharge energy must be greater than the energy required to vaporize 'm' grams of the lubricant (Eq. 3). Effective discharge energy is proportionately related to the calculated discharge energy by an experimentally determined "energy efficiency factor". The mass 'm' of vaporized lubricant will depend on the geometry of the electrodes and of the discharge volume.

$T = T_b - T_i$ [K] Eq. (3a)

$E_{effective} = ½k_eCV_b^2 > mL_v + mL_sT$ Eq. (3b)

Whereas:

$E_{eff.}$ – Effective Lubricant Energy [J]
C – Capacitance
m – Mass of Vaporized Lubricant
L_s – Specific Heat [J/gm-K]
T_i – Dielectric Initial Temperature [K]
k_e – Energy Efficiency Factor
V_b– Breakdown Voltage.
L_v – Heat of Vaporization [J/gm]
T_b – Lubricant's Boiling Point [K]
T – $T_b - T_i$ [K]

3.2 Electric Properties

The discharge of electricity takes place when the potential across the electrodes equals the breakdown voltage. Breakdown voltage for two electrodes can be calculated from the lubricant's dielectric strength (Eq. 4). In general, oils have high dielectric strengths, on the order of about 10-50 kV/mm. In this case, a dielectric strength on the low end of that range would be desired. An expression for the relation between current and total resistance is found by manipulating Equation 3 (Eq. 5). The resistance consists of several components, internal resistance of a capacitor, resistance added by the designer, and line impedance (Eq. 6). Line impedance will play an important role since the system will not be in steady state. It will need to be determined empirically.

$V_b = dE_{ds}$ Eq. (4)

Whereas:

V_b – Breakdown Voltage
E_{ds} – Dielectric Strength [kV/mm]
d – Distance Between Electrodes [mm]

Equation 3 suggests that minimizing the specific heat and the heat of vaporization will result in lower required discharge energy. Synthetic oils, which generally have higher heats of vaporization, generally have film strengths exceeding 3000 psi, while mineral-based oils have film strengths of about 400 psi. However neither is sufficient for the expected pressures of 10ksi-15ksi. It seems that a hard lubricant with a higher tolerance for pressure, such as graphite or molybdenum disulfide, is required. This poses problems, however. The heat of vaporization of a hard lubricant would be significantly higher than of a liquid lubricant. Also, dielectric breakdown in such a lubricant could be permanent and thus make the system ineffective. This can be remedied by insulating the electrodes and the surrounding liquid dielectric. This configuration is also advantageous because it allows more flexibility in the choice of the dielectric medium.

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$$V_b = IR > \sqrt{\frac{2m(L_v + L_s T)}{k_e C}}$$ Eq. (5)

Whereas:

- V_b – Breakdown Voltage
- m – Mass of Vaporized Dielectric
- L_v – Heat of Vaporization [J/gm]
- T – T_b - T_i [K]
- C – Capacitance
- I – Line Current
- R – System Resistance
- L_s – Specific Heat [J/gm-K]
- k_e – Energy Efficiency Factor

$$R = R_{internal} + R_{design} + Z_{line}$$ Eq. (6)

Whereas:

- R – System Resistance
- R_{design} – Design Resistance
- $R_{int.}$ – Internal Resistance
- Z_{line} – Line Impedance

An important aspect of the design is the frequency of the discharges. Assuming, for the purpose of analysis that the breakdown voltage across the electrodes is reached at around t=RC sec, frequency can be easily expressed (Eq. 7).

$$\lambda = \frac{1}{RC}$$ Eq. (7)

Whereas:

- R – System Resistance
- C – Capacitance
- λ – Discharge Frequency [Hz]

Considering that the frequency of the discharges will be at least 3 Hz, the lifetime rating of the capacitor bank should be as high. Because of the considerable depth of the tool assembly, it is desirable that the capacitor bank be located as close to the electrodes as possible. Considering the dimensions of the tubular, custom capacitors should not be required. In general, capacitors used for high-power pulsing applications use charging voltages in the tens of kV, can retain several kJ of energy, and are able to deliver current on the order of 100 kA. Furthermore, they should be able to tolerate significant voltage reversal. Also, some high power capacitors, such as those manufactured by Passoni Villa have built in switches, which could possibly be used to achieve more control of the discharge frequency. Several possible manufacturers of such capacitors are listed at the end of this report. A solid-state amplifier near the capacitor bank would be preferable to a high-voltage transformer due to size considerations. A manufacturer of such devices is also listed at the end of the report.[1]

3.3 Analysis of Deformation[2]

The work done on the expandable tube by the shockwave created by the electric discharge must be constrained to be less than the amount of work required to deform the tube. This work can be calculated using the tube's material properties and its cylindrical geometry. The expression for specific work of deformation is given by Equation 8. The constant m_m, true strain, is defined by Equation 9 and the mechanical constant B is defined by Equation 10. For a cylindrical geometry, E is given by Equation 11.

$$a_s = \frac{B}{1+m_m} E^{(1+m_m)} \qquad \text{Eq. (8)}$$

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Whereas: a_s – Specific Work of Deformation E – Deformation Intensity
B, m_m – Mechanical characteristics of forming material

$$m_m = e_n = \ln(1+\frac{\Delta \ln}{l_0}) \qquad \text{Eq. (9)}$$

Whereas: m_m – True Strain $\Delta l_n/l_0$ – Elongation

In Equation 10, $\Delta l_n / l_0$ is the elongation of the metal. In the case of En-80 steel, with $\Delta l_n / l_0$=0.20, m_m=0.182.

$$B = \frac{E^{m_m}}{e_n^{m_m}} \sigma_b \qquad \text{Eq. (10)}$$

Whereas: $E - \frac{r}{r_0} - 1$ m_m – True Strain
$e_n - e_n = m_m$ σ_b – Yield Strength

$$E = \frac{r}{r_0} - 1 \qquad \text{Eq. (11)}$$

Whereas: E – Deformation Intensity r_0 – Original Radius
r – Final Radius

In Eq. 11, the radius referred to is the inner radius of the tube.

The total work of deformation is a function of the specific work of deformation and the volume of the material deformed. The work done by the discharge on the tube must be no greater than the work required to expand the tube to its final radius.

$$W_D < a_s V_w \qquad \text{Eq. (12)}$$

Whereas: a_s – Specific Work of Deformation V_w – Volume of Deformed Material
W_D – Work Due to Discharge

An expression relating the maximum amount of work can be constructed by assuming a discharge volume of axial length β, and an outer radius r_0; the outer radius being equal to the inner radius of the unexpanded tube. The final outer radius will be designated by r. The volume of the deformation is given by Equation 13, ε is defined in Equation 9, and m_m=0.182.

$$V_w = 2\beta(r^2 - r_0^2) \qquad \text{Eq. (13)}$$

Whereas: β – Axial Length of Discharge Volume; r – Final Radius; r_0 – Original Radius; V_w – Volume of Deformed Material

Performing this calculation for a tube that expands from a 4.77" I.D. to a 5.68" I.D. yields ε=.191. Assuming β=.04m for a hypothetical example produces V_w =.005809 m^3. Noting that the yield strength range for En-80 steel tubes is 48.26x10^7 N/m^2 (70 ksi) to 65.50x10^7 N/m^2 (95 ksi), B is found to range from 48.69 x10^7 N/m^2 to 66.08 x10^7 N/m^2. Therefore, the specific work, a_s, of deformation ranges from 5.82 x10^7 N/m^2 to 7.90 x10^7 N/m^2. For this particular volume and radial expansion, the amount of work required to expand the tube is on the order of 460 kJ to 340 kJ. Hence, the work done on the tube due to the discharge cannot exceed 340 kJ. However, the expected energy of the discharge is far lower. The pressure produced by the discharge must also be limited. The yield strength of En-80 steel is 70-95ksi. The pressure produced by the discharge can therefore not exceed 70ksi. Again, no problems are foreseen since the expected maximum pressure due to the discharge will be around 15ksi. However, should the stated constraints be exceeded, the results would be unpredictable, and control over the process could be lost.

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4.0 Conclusions and Recommendations

4.1 Conclusion

An initial theoretical analysis was performed on a Hydro-Electric assisted lubrication system. A basic calculation was completed and proves feasibility on a theoretical level. The Hydro-Electric assist concept will effectively increase the lubricant pressure by implementing the device in a discharge chamber near the cone surface. The discharge expansion should create a pressure impulse allowing more lubricant to flow between the tool and the tubular, thereby reducing the friction. The preceding formulae give general constraints for the design and the included figure provides a general guide for system layout. This is a complex high-tech solution requiring experimental investigation to validate the concept and expose unforeseen issues. While there will certainly be challenges in developing this concept, the design is very promising. Further experimental investigation seems to be in order.

4.2 Recommendation

The next steps are to validate the Hydro-Electric concept. In order to validate the feasibility two projects should be completed. The first project will focus on obtaining lubricant and system values for the equation variables and performing an accurate theoretical analysis. The second project requires actual testing of a Hydro-Electric system in an expandable tubular environment. Testing can either be performed internally or at a suitable testing facility.

In the case of internal testing, a test apparatus will need to be design and built. An example of a test apparatus design follows. The determination of the specific capacitances, resistances, impedances, and voltage required for implementation should be found experimentally. The process values for a given lubricant could be determined by utilizing a discharge volume with piezoelectric sensors. Piezoelectric sensors are small, can withstand extremely high pressures, and produce electric outputs that are easily digitized and quantified for analysis. There are also several possible ways to regulate the power delivered in the testing apparatus. Regulation of system resistance using potentiometers would be an effective way to regulate the discharge power. The capacitor bank could be designed to enable quick removal or addition of capacitors. A digital oscilloscope can be connected to the transmission line via a voltage divider to monitor system voltage. Finally, the current should be measured with a Rogowski coil, which uses the Hall effect to measure high currents. This is a brief example of the details that must be considered to validate the concept.

5.0 Appendix

5.1 Supplemental Information - Suppliers of Capacitors and Related Products

Passoni Villa	www.passoni-villa.com (Capacitors)
Aerovox	www.aerovox.com (Capacitors)
Richardson Electronics	www.industrial.rell.com (Ignitrons)
Darrah Electric	www.darrahelectric.com (Power Semiconductors)
Magnet-Physik	www.magnet-physik.de (EMF Forming)
Magneform	www.magneform.com (EMF Forming)

5.2 References

[1] P. Sarkar, et al., "Operation of a capacitor bank for plasma metal forming." Pramana. Vol.55, Nos 5&6:941-945 <http://www.iisc.ernet.in/pramana/nd2000/P53.pdf>

[2] I.V. Belyy, et al., *Electromagnetic Metal Forming Handbook*. Trans. Altynova. 1996. < http://www.mse.eng.ohio-state.edu/%7EDaehn/metalforminghb/index.html>

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Initial Information Data Sheet

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Title Line Two:	---
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Formal Drawings?	No
Application Type:	Provisional
Docket Number:	EGT-2003-25
Secrecy Order in Patent Application:	No

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